Volume 23 JANUARY, 1939 Number 1

BULLETIN
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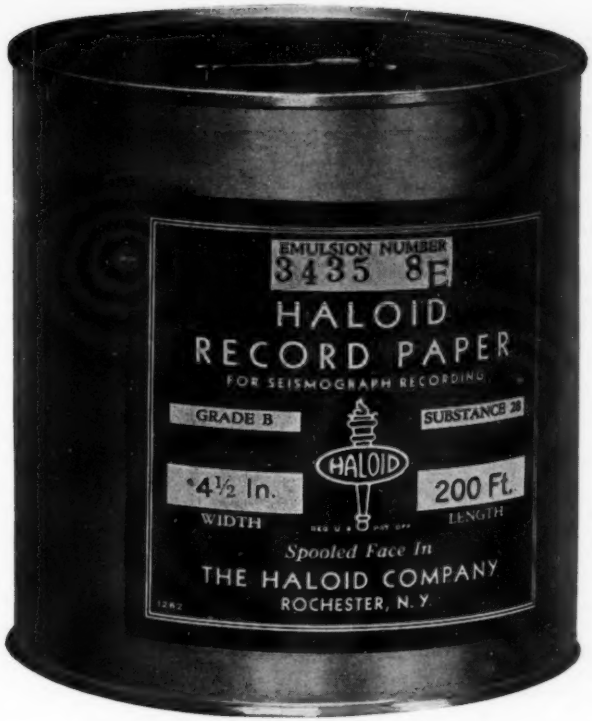

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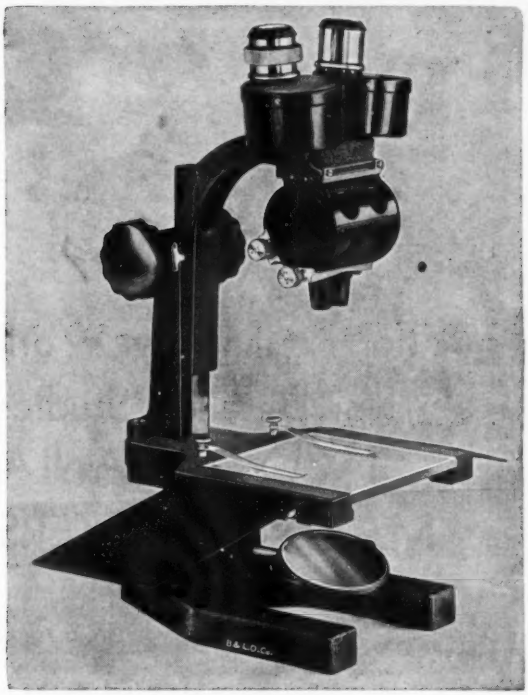

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Volume 23 Number 1

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JANUARY, 1939

BOTTOM SEDIMENTS OF LAKE PONTCHARTRAIN, LOUISIANA[1]

R. A. STEINMAYER[2]
New Orleans, Louisiana

ABSTRACT

Lake Pontchartrain, Louisiana, originated from the Gulf of Mexico by a delta finger of the Mississippi River uniting with the mainland and enclosing a part of the gulf between the finger and the mainland. After its isolation, connection was and is still maintained between the lake and the gulf through tidal channels.

It originated from a mixed continental and marine environment and is slowly passing into a continental environment with corresponding changes in its medium from marine to brackish to fresh water. Inasmuch as the environmental changes have not been progressively uniform at all times and at all places, there are marked variations in the character and distribution of the sediments and the associated life.

In general, wave action, littoral currents, and inflowing streams are the controlling factors in the textural distribution of the sediments, which are coarse along the outer margin where water activity is greatest and fine in the deep and quiet waters of the lake. Bottom topography does not exert as important an influence as the foregoing factors in the textural distribution of the sediments.

Aside from anomalies, the organic content is high where the texture is fine, and low where the texture is coarse. The organic matter of the lake seems to be principally vegetable in origin.

The arrangement of the sediments of Lake Pontchartrain into distinct beds, the regularity in areal as well as vertical distribution, and the compacting of material increase with depth.

INTRODUCTION

This article is a summary of the main features of geologic interest that were included in an original report on "The Bottom Sediments of Lake Pontchartrain," the studies of which were carried on with the aid of a grant from the committee on sedimentation of the Division of Geology and Geography of the National Research Council.

The original report on file in the office of the Division at Washington, D. C., includes the history of the discovery and establishment of settlements on the shores of Lake Pontchartrain; the location, size, and shape of the lake; the origin and physical history of its develop-

[1] Manuscript received, June 30, 1938.

[2] Tulane University.

ment; the climatology of the region; the procedure, methods, and apparatus used in the field investigation; the contraction or enlargement of its margin; the filling-in or deepening of its basin; the areal distribution and types of its sediments, their stratigraphic distribution, and their physical and chemical characteristics; and a brief discussion of its molluscan life, both past and present.

GENERAL RELATIONS OF LAKE PONTCHARTRAIN

Lake Pontchartrain is situated in the southeast corner of Louisiana near the Louisiana-Mississippi State line between parallels 30°00′ and 30°25′ N., and meridians 89°45′ and 90°25′ W. (Fig. 1). As measured in an east-west line, along the 30°10′ parallel, the lake is 40.8 miles long, and as measured in a north-south line along the 90°10′ meridian, it is approximately 25 miles wide.

Table I shows the total area and volume of the lake as well as the sub-areas and sub-volumes and depths between two or more successive contours with their corresponding percentage of the total area or volume.

TABLE I

AREAS AND VOLUMES OF LAKE PONTCHARTRAIN BETWEEN SUCCESSIVE HYDROGRAPHIC CONTOURS

Contour Location	*Average Depth in Feet*	*Area Square Yards*	*Per Cent of Total Area*	*Volume Cubic Yards*	*Per Cent of Total Volume*
16	16	23,400,000	1.19	124,500,000	0.7
15–16	15.5	229,300,000	11.6	1,181,000,000	15.7
14–15	14.5	384,000,000	19.70	1,893,000,000	25.1
13–14	13.5	290,000,000	14.70	1,304,000,000	17.4
12–13	12.5	198,000,000	10.00	800,000,000	10.6
11–12	11.5	177,000,000	9.00	680,000,000	9.1
10–11	10.5	159,000,000	8.10	556,600,000	7.5
9–10	9.5	142,700,000	7.26	450,000,000	6.1
8– 9	8.5	73,200,000	3.75	207,300,000	2.7
0– 8	4	288,000,000	14.70	384,000,000	3.1
Total		1,964,600,000 or 635 square miles	100.00	7,548,000,000 or 3.2 cubic miles	100.00

Mean low-water depth = 11.5 feet

Aside from its easterly lobe, the lake (Fig. 1) is irregularly elliptical. Its basin is saucer-shaped with many irregularities in the slope from the rim to the bottom as well as irregularities in relief. In many places its perimeter is only apparently defined because of the absence of a pronounced beach ridge and the screening of the shore line by the encroachment of marsh vegetation into the lake.[3]

The most striking feature on the contour map and the cross sec-

[3] "Atchafalaya-Pontchartrain Basin," Sheets 1 and 2, *U. S. Army Eng. Corps.*

tions is the very gentle slope of the basin along the west side of the lake between parallels 30°05′ and 30°15′, which implies a considerable filling-in of the lake on this side in comparatively recent time. Some of the materials, no doubt, were deposited there by the sediment-laden waters from the rivers, bayous, and Pass Manchac, others by lake currents and other causes, but most of them probably accumulated there when the water of the Bonnet Carre Crevasse spilled into the lake for 8 years (1874–82) and deposited its suspended materials into the quiet water. Other low gradients occur, principally on the northwest and north sides of the lake where Pass Manchac, the Tangipahoa, and the Tchefuncta rivers and large bayous, carrying sediments either from Lake Maurepas or from the uplands on the north, deposit their loads in the lake near their mouths.

Unfortunately, very few hydrographic surveys were made of the lake in the past and where earlier surveys were made and the records are available they involve principally its easterly lobe and narrow tracts along its southern shore. Figures 1 and 2 are a composite map constructed by the writer from U. S. Coast and Geodetic Survey hydrographic Sheets 3961 and 10556, surveyed, respectively, in 1917 and 1870. The contours have been drawn by the writer and do not appear on the sheets. By comparison of the perimeters, it may be readily seen that only slight changes have taken place in its shore line in the interval of years. In general, it appears as though the recession has exceeded the advance of the shore line. Between Point aux Herbes and the Chef Menteur it has receded approximately $\frac{1}{8}$ mile at an annual average rate of about 14 feet.

Another recession occurred on the northeasterly side of the lobe midway between the Chef Menteur and the Rigolets; and between the Rigolets and Grand Lagoon, the shore line advanced in some places and receded in others, with the recessions exceeding the advances in numbers and distances.

Grand Lagoon has contracted considerably during the years and here the shore line is advancing into the lake. Between Grand Lagoon and Big Point, the advances and recessions balance, and from Big Point to Point Platte, the land has advanced slightly into the lake.

A better picture of the shore-line changes in historical time occurred in that part of the lake between Bayou St. John and the New Basin Canal. There has been a progressive recession of the shore line at this place from its original position in 1808 to its 1917 shore line. At its maximum point the shore line receded approximately 830 feet during an interval of 109 years, with an average annual recession of slightly less than 8 feet.

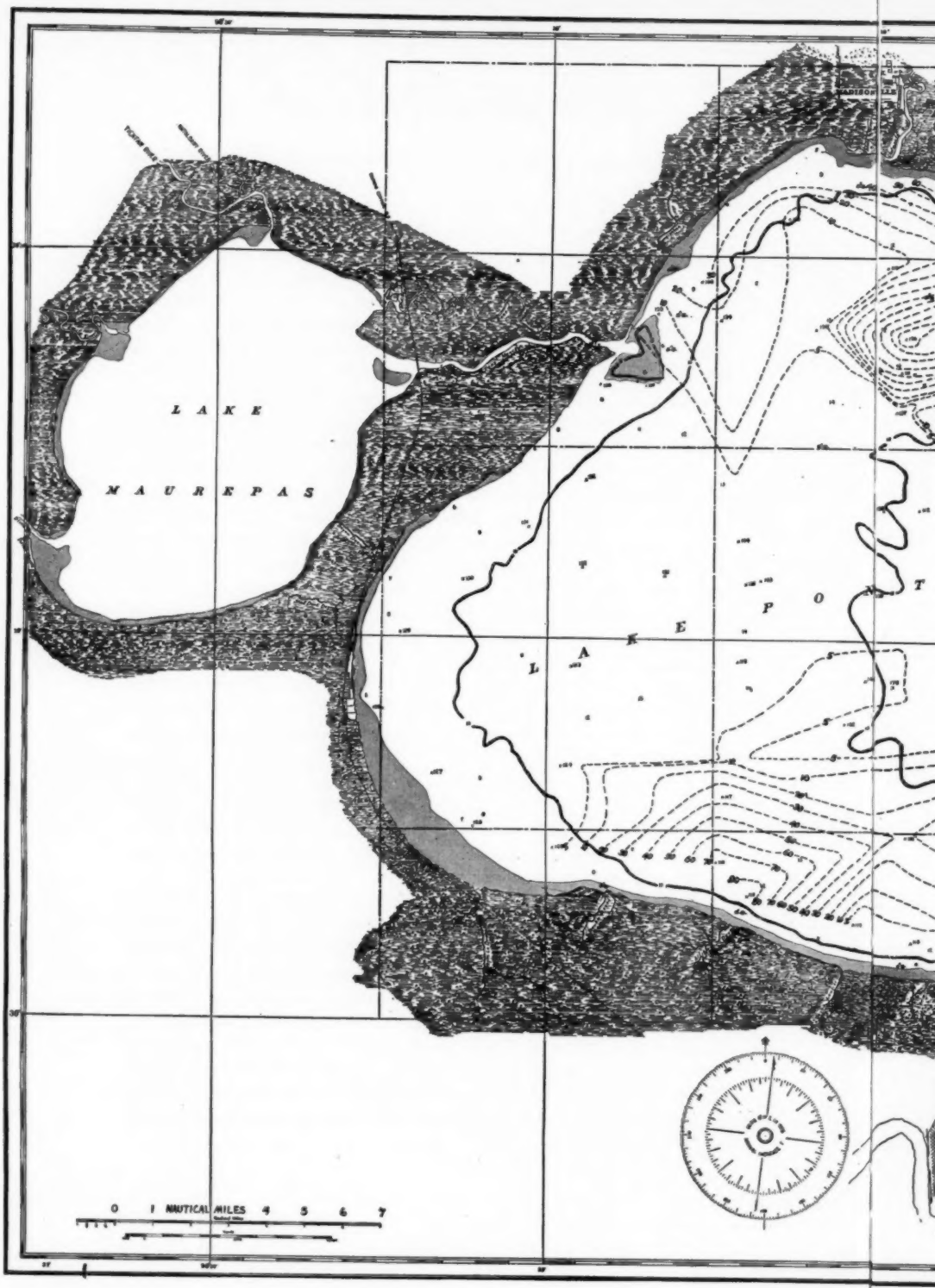
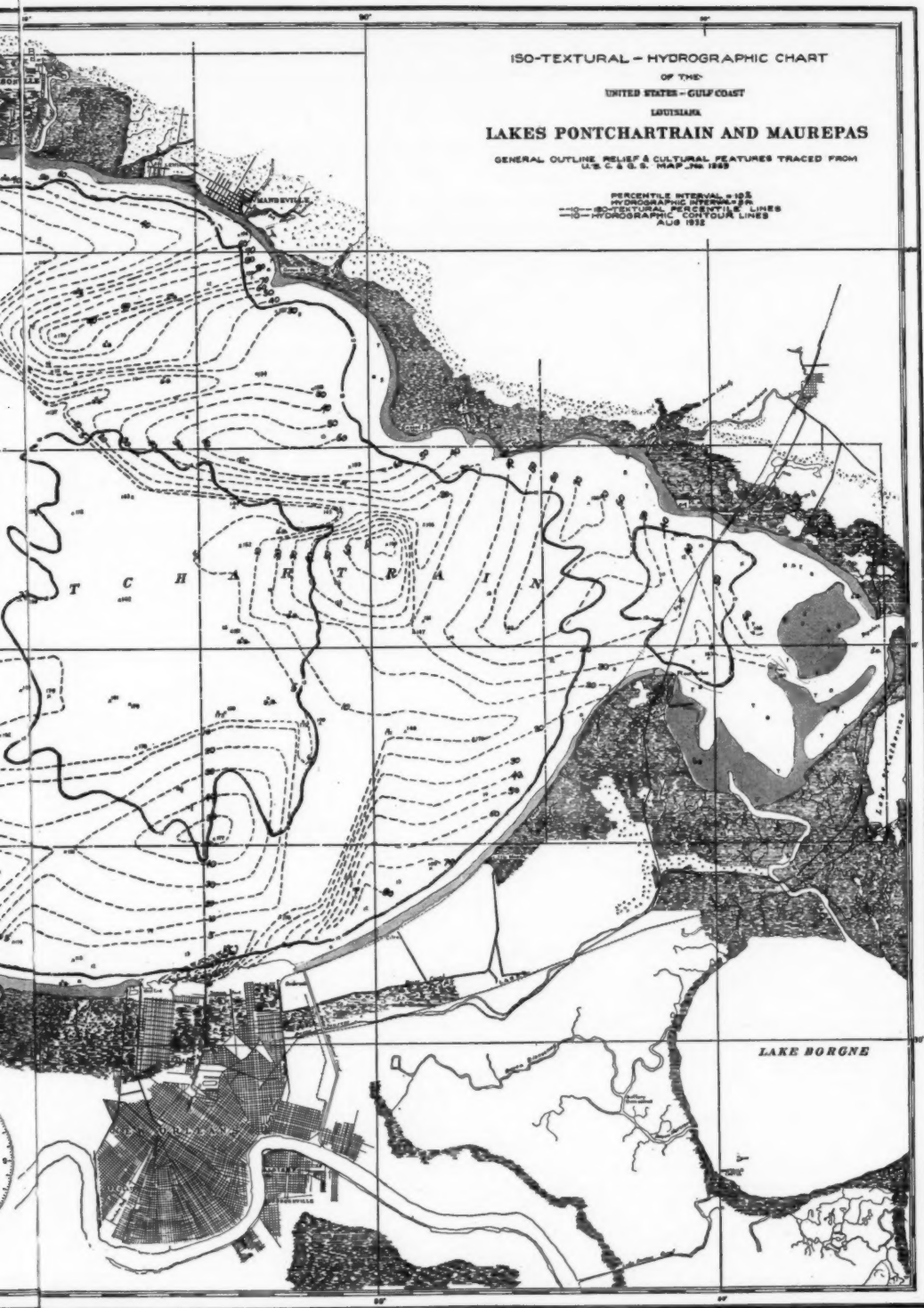


FIG. 1


ISO-TEXTURAL – HYDROGRAPHIC CHART
OF THE
UNITED STATES – GULF COAST
LOUISIANA
LAKES PONTCHARTRAIN AND MAUREPAS
GENERAL OUTLINE, RELIEF & CULTURAL FEATURES TRACED FROM U.S.C. & G.S. MAP No. 1949
PERCENTILE INTERVAL = 10%
HYDROGRAPHIC INTERVAL = 5ft.
—10— ISO-TEXTURAL PERCENTILE LINES
—10— HYDROGRAPHIC CONTOUR LINES
AUG 1932
T C H A R T R A I N
LAKE BORGNE

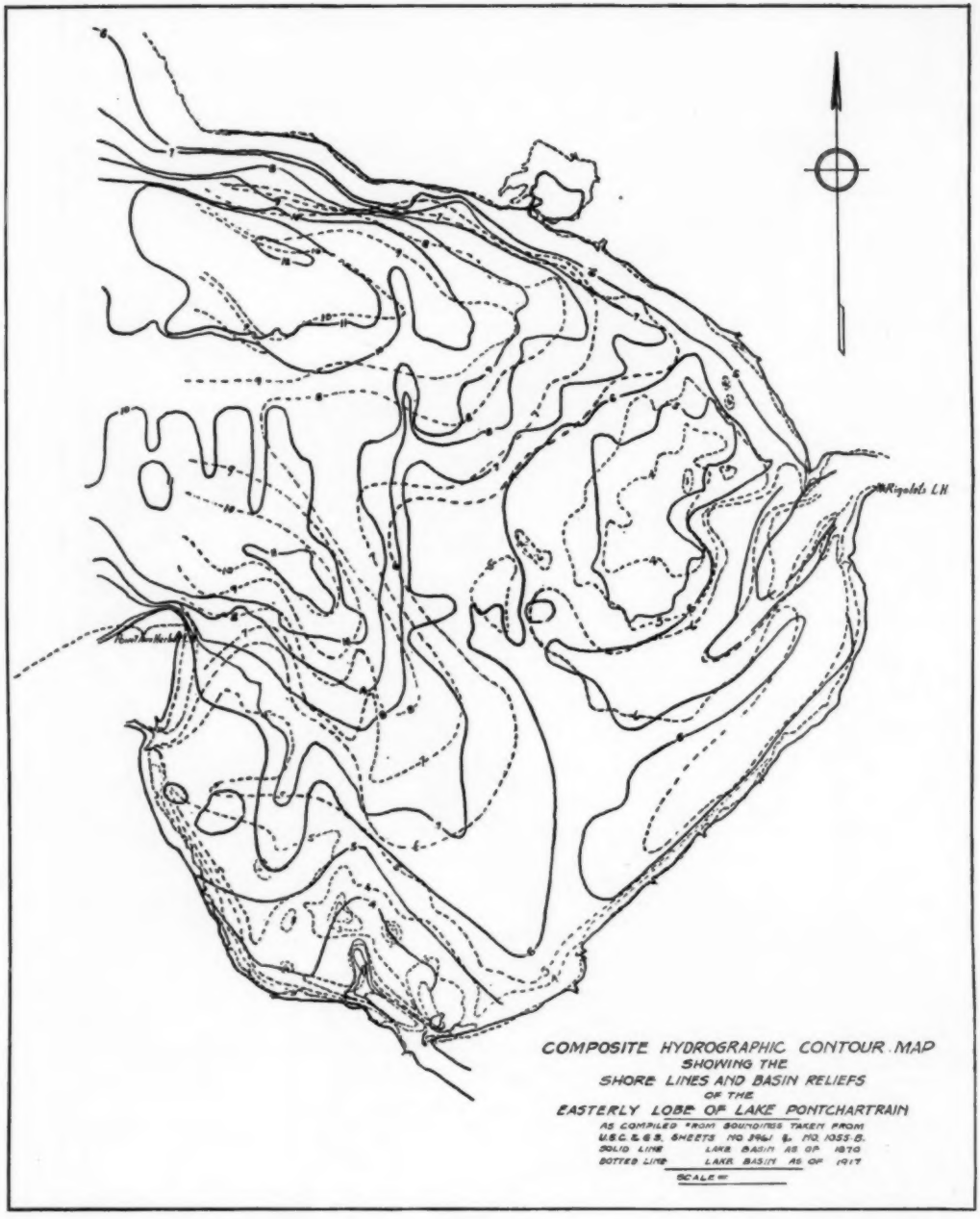

Rigolets LH
COMPOSITE HYDROGRAPHIC CONTOUR MAP
SHOWING THE
SHORE LINES AND BASIN RELIEFS
OF THE
EASTERLY LOBE OF LAKE PONTCHARTRAIN
AS COMPILED FROM SOUNDINGS TAKEN FROM
U.S.C. & G.S. SHEETS NO. 3961 & NO. 1055-B.
SOLID LINE LAKE BASIN AS OF 1870
DOTTED LINE LAKE BASIN AS OF 1917
SCALE=

FIG. 2

The relief of the easterly lobe of the lake basin is very irregular, probably because of the great agitation and scouring of its bottom sediments by the outward and inward moving tidal waters, the storm and wind waves, river and bayou currents, and artificial causes. In its easterly lobe, the lake still maintains connection with the open water of the Gulf of Mexico through its tidal channels, the Chef Menteur and the Rigolets (Fig. 2). These water connections due to their constantly reversing currents, have excessively deep channels, in some places more than 90 feet, and may be cited as good examples of thoroughfares. Material, transported by littoral and other longshore currents in the open water in front of them, is seized by the reversing tidal currents and deposited in the quieter water of the lobe to form its tidal deltas. Typical lakeward-facing submerged tidal deltas have formed at the head of both of these thoroughfares (Fig. 1).

The lake in its general physiographic and geologic relations lies wholly in the Mississippi delta of the Gulf Coastal plain and is recent in origin. Fronting its northern rim are the seaward-facing scarps of the Hammond and Pensacola terraces of Pleistocene deposits which extend into the delta where they merge with its recent terraces.

The delta proper, aside from the natural levees that border its rivers, is a flat, low, featureless plain dotted with innumerable lakes and traversed by tortuous bayous and rivers. On the high ground, between a part of the southern shore of the lake and the northern levee of the Mississippi River, almost surrounded by water, stands the "Island City," New Orleans.

ORIGIN AND PHYSICAL HISTORY OF DEVELOPMENT OF LAKE PONTCHARTRAIN

Much has been written and more has been said by investigators speculating about the origin of lakes Maurepas, Pontchartrain, and Borne. Some believed that the lakes originated from crustal disturbances creating synclinal depressions; others have postulated that they were formed by the waters of the Mississippi spilling over its flood plains; still others have said that these lakes occupied an abandoned channel of the "Father of Waters"; while most investigators have adhered to the theory that Lake Pontchartrain and its sister lakes developed, or are developing, by the irregular growth of the delta fingers back against the banks which outline the ancient estuary, having left a series of unfilled basins between them, which were formerly in direct connection with the open sea, and which still maintain their marine connection through tidal channels.

A casual observation of any good topographic map of the lower

delta of the Mississippi River will reveal that the sub-aërial part of the delta is made up mainly of salt-water marsh lands, at or near mean gulf level, which, before the confinement of the waters of the river between artificial levees, created during the short historic time since white men first settled in this country, were overflowed almost annually by its flood waters. The lands, themselves, are dotted by innumerable lakes of various sizes and shapes and traversed by tortuous bayous. Near their gulfward and soundward margins they are irregularly fringed by narrow embayments and corresponding projections of the marsh lands, with many islands, spits, and bars jutting into the surrounding water for considerable distances beyond their shore lines.

The larger portions of these lands, with exceptions that are noted in the following paragraph, are so soft, unstable, and non-indurated that there is not sufficient area of solid ground on which to build a city until New Orleans is reached, 110 miles from the gulf.

The exceptions are the most striking topographic features of the lower delta—the long, narrow strips of high solid ground immediately adjacent to, and on both sides of, the main channel of the Mississippi River, near the heads of the present passes, and paralleling Bayou Sauvage and Bayou La Loutre.

The closing of former large distributaries of the river, of which bayous Sauvage and La Loutre are remnants, by a ponding and silting of their channels, deflected the main current in the river, and probably produced its anomalous bends slightly above, at, and below New Orleans. One of these former large distributaries embouched from the crest of the second bend in the river, above New Orleans.

The other and more recent headed from the river near the present settlement of Poydras. These are still points of structural weakness in the levees and are subject to crevasses during periods of high water.

Bayou Sauvage formerly embouched from the river as an important pass and flowed east by northeast for a considerable distance as an unbranched channel before it divided and sent out its secondary distributaries, some of which eventually united with the mainland near the mouth of the West Pearl River. Here they enclosed part of the water of the ancient gulf estuary, now known as Lake Pontchartrain, between the mainland and the high ground near the river, with smaller estuarine bodies of water, such as Lake Catherine, forming between its fingers. The traces of the natural levees bordering this former large distributary can be plainly followed on a map[4] from a point on the Gentilly Road west of New Orleans to its terminus near the Louisiana-Mississippi State line.

[4] *U. S. Army Eng. Corps*, Sheet 102.

The similarities in type, character, and distribution between the sediments found on, adjacent to, and underlying the Bayou Sauvage ridge and the normal delta sediments forming today in the passes near the mouths of the river further support the theory that the ridge was formed by an ancient pass of deltaic origin.

The inclusion of marine beds between alluvial material as well as the unconformities and the dissimilarities in the formation is due, the writer believes, to dovetailing of marine beds with the sub-aërial part of the delta, caused by oscillations of the sea-level, each rise bringing the sea over the sub-aërial plain where it deposited its marine sediments, and each fall leading to an outward extension of the foreset beds and an erosion of the sub-aqueous and sub-aërial plain.

Lake Pontchartrain is a good example of a lake which has passed through the many environmental changes with corresponding alterations of its sediments and the organisms that lived within them.

After the delta bar had been united with the mainland, the part of the estuary behind it was gradually transformed into a shallow-water area through the combined operation of several agencies. Streams from the land and the innumerable bayous brought down sediments and deposited them near their mouths. Some of this material was subsequently distributed over the lake bottom. Other streams that now enter Lake Maurepas, such as the Blind, Amite, Tickfaw, and Natalbany rivers, and countless bayous, also directly or indirectly through Pass Manchac, added more alluvial material to the lake bottom.

Crevasses, such as the Bonnet Carre Crevasse, which for 8 years spilled the high water of the river into the lake, added and distributed their sediments. Offshore winds blew sand from the ridge and the old shore beach into the lake, and probably caused a lakeward migration of old beach sand dunes. Hurricane winds dashed the sediment-laden waters over the delta bar and these waters backing up into the lake built a wave delta in its eastern lobe. Tidal waters from the Chef Menteur and the Rigolets daily deposited their material into the quieter water of the lake to form a tidal delta (Fig. 1). Finally, in some places, salt-water vegetation secured a foothold in areas of shallow water, and, both by building up to the surface and by advancing over a part of the lake, especially in the vicinity of the sluggish bayous, assisted in the conversion of a part of the area into land.

CLIMATOLOGY

Several factors of climatology are pertinent to a discussion of the sediments of Lake Pontchartrain.

Rainfall.—It is torrential rain that occurs at irregular intervals near New Orleans and its vicinity, not the heavy annual rainfall (59.39 inches), that visibly agitates the water and raises the level of Lake Pontchartrain. During the Good Friday, 1927, rainstorm, covering a wide area, 14 inches of rain fell in 19 hours and raised the lake level 3 feet. Precipitation probably accounted for 6 inches of the total rise. The remainder was due to a combination of wind and tide.

Winds.—The prevailing winds at New Orleans and its vicinity come from the southeast, northeast, and southwest, and the storm winds blow more frequently from the southeast, northwest, and north. The southerly winds generate wind waves and currents that both back up the waters from the Mississippi Sound and tidal waters in the thoroughfares, and also erode and transport with their resulting shore currents sediments along the north shore of the lake—a receding shore line. Similarly, the winds blowing from northerly directions erode, sort, and transport the sediments along the southern shore of the lake—also a receding shore.

Hurricanes.—The Gulf Coast of Louisiana, at not infrequent intervals, during late summer and early fall, is swept by hurricanes that originate in the West Indies. A notable one swept over Louisiana on September 29 and 30, 1915. The normal elevation of the lake is about 0.3 foot above mean gulf level, but during this storm it rose to a height of 13 feet near the woods of Frenier, and 6 feet above that level in the open spaces near Pass Manchac. In addition to battering a high railroad bed on the west side of the lake, other changes, both in the configuration of its shore line and in the character of its sediments, were brought about by the violent agitation and tremendous shoreward sweep of the lake waters. Probably the greatest contribution of hurricanes consists in adding to the bottom sediments and commingling land-borne material, such as coarse sediment and vegetable matter.

Tides.—In general, it may be stated that insofar as Lake Pontchartrain is concerned, tides, themselves, are of little importance in transporting or modifying sediments except near the tidal thoroughfares. On the other hand, an incoming tide accompanying southerly winds would effectively assist wind waves in agitating and transporting sediments.

Relation of sediments to streams.—Few important streams and those only on the northern side, such as the Tangipahoa and Tchefuncta rivers, and bayous Lacomb, Bonfouca, and others, flow into the lake. Some of these southerly flowing streams have sufficient competency to transport sediments and subsequently deposit them near their mouths to form delta bars. At times, considerable living

vegetation is floated by some of these streams into the lake. On the opposite side, many bayous and outfall drainage and sewerage canals slowly discharge their humus-laden fine sediments into the lake.

Relation of sediments to crevasses.—All natural breaks in the levee systems of streams through which certain amounts of their waters (generally flood waters) are diverted and discharged are termed "crevasses" in Gulf Coastal terminology.

Crevasses have occurred in the levee system of the Mississippi River since the river first acquired its natural levees. Before man began to build up and strengthen the levees created by nature, crevasses occurred at many places during every period of high water. After the construction of the artificial levees, crevasses decreased in number, but increased in severity in the volume and velocity of the escaping waters because the building-up and lengthening of the levee system of the river increased at its flood stages. In 1874 the flood crest of the river on the Carrollton gauge was 15.7 feet. In 1927 the flood stage for the river on this gauge was 21.0 feet and should have been approximately 24.0 feet, but breaks (crevasses) in the levee occurred considerably before forecast for attainment of the crest stage.

The following description of the Nita Crevasse impresses one with the quantity of waters discharged through breaks in the levees.

> The Nita Crevasse, which came into existence in 1890, reached a discharge of 402,556 second-feet, yet flood stage at Carrollton, about 58 miles below, was lowered only 1.6 feet. The crevasse carried about one-third of the discharge of the entire river.[5]

At the time of the break, the crevasse was approximately 600 feet in width by 15 feet in depth, the width rapidly increasing to 3,000 feet.

> The Colorado River, which created such havoc in the Imperial Valley of California, has a maximum discharge of 150,000 second-feet, or about one-third that of the Crevasse. Niagara River, which, with its cataracts and rapids, is one of the wonders of the world, has a normal discharge of about 200,000 second-feet, or one-half of the discharge of the Nita Crevasse.[6]

On the Donaldsonville, Louisiana, sheet may be seen the delta built in the swamp by the silt-laden waters from the Nita Crevasse. This delta, consisting of low, irregular hills is marked "alluvial deposits from Nita Crevasse."

The Nita, Bonnet Carre, and Sauve Plantation crevasses are only a few examples of the many similar crevasses that have come into ex-

[5] J. A. Okerson, "Outlets for Reducing Flood Heights," *Mississippi River Commission* (1914), p. 8.

[6] *Ibid.*

istence in historical time and the countless hundreds of others that must have been cut previously on the left bank of the Mississippi River. All of them probably added a part of their sediment-laden waters to the present lake, or to the much larger ancestral lake that originated from the gulf and of which Lake Pontchartrain is only a remnant, thereby contracting and filling in the lake basins with their river and flood-plain sediments. By the time the flood waters reached the lake, they had low competency and could transport only the finest material either in a state of colloidal suspension or in solution. The materials, both organic and inorganic, transported as colloidal suspensoids, were further coagulated and eventually precipitated as clay gels when the fresh river waters commingled with the brackish lake waters through the action of electrolytes in solution or colloids.

These clay gels later became a medium for the absorption of gases and organic matter, and from some of them, as exhibited by samples 119 and 120, emanated strong fetid odors.

The bottom sediment map shows a considerable area of the lake extending from its west side to its center, consisting of clays (ultra) and silts of comparatively recent crevasse origin.

COLLECTING SAMPLES

The samples of the bottom sediments of Lake Pontchartrain, examined by the writer, were either collected by him (summer, 1931) or had been previously collected by drilling contractors employed by the Board of Levee Commissioners of the Orleans Levee District for their Lake Shore development project and the Shushan Airport project.

Samples were secured on both of the foregoing projects by driving a core barrel inside of a casing.

In collecting samples from the lake proper, a charted course was followed and attempts were made to secure samples at regular intervals, approximately 3 statute miles apart. While taking a sample the boat engine was idled, the compass bearing and log distance noted, the sounding line was cast, and the sample was taken before the boat began to drift.

Three different types of sampling devices were used, two of which were designed by the writer (Fig. 3) and the third was the U. S. Coast and Geodetic Survey snapper type sediment cup No. 112. From actual experience in the use of these sampling devices, it was found that the adaptability and efficiency of each of them varied with the character of the sediment, that is, soft sediments and oozes were too liquid to adhere to the inner side of the brass core barrel and too soft to snap the spring of the snapper cup, but were easily collected by sinking the

aluminium cup into them and allowing the material to flow over its rim into the cup.

Plastic material, such as heavy clays, were too stiff for the aluminium and snapper cups, but clung tenaciously to the inner side of the brass core barrel. On the other hand, sediments, such as loose sand, gravel, and shell which could not be displaced by the aluminium cup and washed out of the core barrel as it was drawn to the surface, were satisfactorily collected in small amounts by the snapper cup.

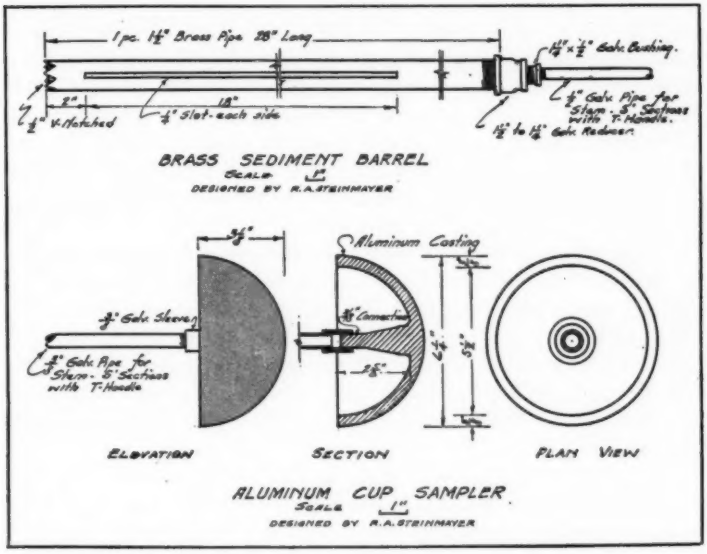


FIG. 3

NATURE OF SEDIMENTARY ANALYSIS

From a total of approximately 1,000 samples, 180 represent the immediate sub-aqueous surficial sediments of the lake and the remainder represent the sub-aqueous subsurface material (the material 5 or more feet below the present lake bottom).

Classifications of samples.—The sediments of all the samples taken from the lake were divided into four general classes: clay, silt, gumbo, and sand. Each class, except sand, was further divided into sub-classes on a sand-content basis: sandy silt, sandy clay, and sandy gumbo. Sand, in turn, was further classified on its content of either of the first two into clayey or silty sand.

Character of Material	*Per Cent of Total Mass Retained on 200-Mesh and Larger Screens*	
		Average
Sand	80–100	88.83
Silty sand	70– 79	74.50
Clayey sand	50– 69	51.90
Sandy silt	30– 49	33.2
Sandy clay	10– 29	22.2
Silt	4– 9	6.24
Clay	0– 4	1.74

Frequency of grain distribution of samples.—The frequency distribution of the various-sized particles was determined with a U. S. standard sieve series, ranging from 20-mesh (0.84 millimeter) to 200-mesh (0.074 millimeter) inclusive, and the mass of their respective-sized particles was determined by weighing on an analytical balance. No attempts were made further to divide or describe the sub-classes of sediments on the basis of the associated shell or organic matter. Nevertheless, they were not disregarded and the necessary chemical determinations were made by which each of them could be expressed in terms of percentage of the total mass.

Color of samples.—In considering color names for identifying the color sensations of the bottom sediments of Lake Pontchartrain, two distinct classes must be kept in mind: (1) the color produced by a single mineral or substance; (2) the color produced by a mixture of minerals and substances. Inasmuch as all of the sediments consisted of mixture, and furthermore as no attempts were made to differentiate the mixture into its component parts, only the second class was considered in the problem.

The color of each sample of the immediate sediments of the lake was matched on both a wet and dry basis against a dictionary color shown on a series of color plates,[7] the order of which follows the spectrum.

It has been found that in matching colors of sediments certain factors, such as fatigue of the eyes, different illuminants, texture of the surface of the sample, tilting of the plane of the sample, surrounding hue, and especially the degree of saturation of the sample exert tremendous influences on the appearance of any color. The writer was especially interested to note whether there was a harmony of change between the wet (saturated) and the dry (110°C.) samples, that is, whether a certain definite wet-color index would always yield the same dry-color index.

In general, it may be stated that color remains a relative term of

[7] Maerz and Paul, *Dictionary of Color*. McGraw-Hill Book Company, New York (1930). This book contains 56 plates and more than 7,000 colors.

little value in sub-aqueous sediments until a saturation basis of comparison is established.

Odor of samples.—All samples were tested for odor and, where easily detected, it was arbitrarily expressed in degrees as faint, medium, and strong. Comparison of the degree of odor of the fetid samples shows distinctly that the degree of odor is no guide to the organic content of the sample. Sample 146, with a high organic content, possesses a strong odor, whereas sample 169, with the same degree of odor, possesses less than one-third of the organic content of sample 146.

Neither was odor a criterion of living matter, at least as determinable by megascopic examination. Sample 146, in which abounded live mollusks, had a distinct fetid odor though other samples also containing shell life, such as 130, 140, 147, and 168, were either without odor, or had only faint odors. Probably the odor of some of the sediments is due to the associated nitrogenous organic compounds, and is an approximate measure of their degree of decomposition.

Associated organic matter.—The presence of humus matter and comminuted vegetable matter was also noted during the classification of the samples, the former giving to the sample a dark color and the latter separating from the sediments during the screening operation. Humus matter generally implied high organic content, although samples 154 and 159 are exceptions to the rule. Comminuted vegetable matter, partly altered and decayed, on the other hand, always denotes high organic content when it occurs in measurable quantities in the samples. From the fact that high organic content always occurs with high vegetable content and seldom with high animal content, the inference may be made that most of the organic content of the sediments of Lake Pontchartrain is of vegetable origin.

ISO-TEXTURAL CHART

The combined iso-textural and hydrographic chart (Fig. 1) was constructed by superimposing on a general outline map of the lake lines connecting all points where sediment had equal percentiles of particles retained on a graded U. S. standard sieve series between and including the 200- and the 20-mesh, and lines connecting all points of equal depth.

Relation of texture to bottom topography.—A comparison between the iso-textural percentile lines and the hydrographic contours (Fig. 1) shows that, although there is a slight general relationship between texture and bottom topography, other factors such as wave action and currents in the lake exert greater influences on the distribution of the

sediments according to their texture than the configuration of its basin.

With respect to topography, it may be seen that the coarse sediments are distributed near the margin and the steep slopes, and the fine material occurs on the gentle slopes and the bottom of the basin.

The following are, however, notable exceptions to the general relationship between texture and bottom topography. On the west side of the lake the fine sediments extend over a large area from the rim of the lake down the gentle dip slope to the bottom of the saucer. On the northeast side, the coarse sediments extend well down the side of the steep slope of the basin, at that place, to the broad flats near the bottom of the basin. North of the intersection of the 90° meridian and the 30°10′ parallel occurs a localized textural island of coarse material on a sub-aqueous ridge, surrounded by finer sediments. A similar textural island of coarse material surrounded by finer material occurs on the flat near the intersection of the 90°05′ meridian and the 30°05′ parallel, a few miles north of New Orleans, and in front of every stream, bayou, and canal are narrow areas of fine material that extend from the shore line well into the lake.

Relation of texture to waves and currents.—Lake Pontchartrain, although a lake of considerable size and freedom of expanse, is a comparatively shallow lake and consequently at times even the sediments in the deepest part of the lake are agitated and moved by waves. Its northern and southern shores with their steep slopes face the greatest stretch of open water and are swept by southerly and northerly winds during most of each year. These shores consequently receive the largest amount of wave energy. The dominant winds strike the shore lines at angles and set up counteracting longshore currents that sort out, transport, and deposit the coarse sediments to form the beaches and ridges, namely, Ragged Point and Green Point. The longshore currents generally flow westward along the southern shore. The textural distribution of the sediments, however, is not merely a problem in wave action and littoral current, but is further complicated by tidal and stream currents. The tides assist in the westerly drift of the sediments along the northern shore, while the streams set up counter and eddy currents in the lake that bring about a heterogeneous textural distribution of the material to form coarse textural islands and spits, the fine textural cove between Ragged Point and Green Point, and the fine textural troughs, one extending out from Seabrook and the other, irregular one, leading into the east lobe of the lake. The west side of the lake, with its gentle slope and shallow water, is a comparatively stagnant area as far as wave action and currents are concerned and

consequently very little textural sorting of the sediments has taken place except near the very rim of the lake where a narrow strip of coarse sediment occurs. No sharp demarcation exists in the textural distribution of the sediments and in general there is an imperceptible, textural, lateral gradation from the coarser into the finer sediments. The size of the sediment varies from coarse to fine out from the shore in some places and at other places varies in the other direction. A section normal to Little Woods is an example of the former, and a section normal to Bayou Lacombe is an example of the latter.

A section normal to Spanish Fort, however, shows that the grading of the sediments may be reversed. From the shore line into the lake, the material grades from coarse to fine but farther out it grades back to coarse on the same unchanging lakeward slope of the basin.

ORGANIC CONTENT OF SEDIMENTS

The organic content of the sediments was determined by ignition loss, and the amount of organic matter in each sample was expressed in percentage of a known mass of the sample previously dried at 110°C. The results of the determinations show variations from a minimum 0.216 per cent in sample 155 to a maximum 24.0 per cent in sample 14. This maximum value, however, is an anomaly which can not be correlated with the general classes of lake sediments and represents a polluted sample. Table II shows the average percentage of organic material for each of the classes and sub-classes of sediments from Lake Pontchartrain.

TABLE II

	Per Cent
Sands	0.528
Silty sands	1.55
Clayey sands	1.98
Sandy silts	2.3
Sandy clays	2.68
Silts	4.90
Clays	6.72

ISORGANIC CHART

The isorganic chart (Fig. 4), like the iso-textural chart (Fig. 1), was constructed by superimposing on an outline map of the lake, lines connecting all points in the lake having equal percentiles of organic matter.

Relation of organic content to bottom topography.—A comparison of the isorganic chart with the hydrographic chart (Fig. 1) shows that the organic content of the sediments is high (exclusive of areas of pollution and abstraction) in the deeps and the gentle slopes, and low

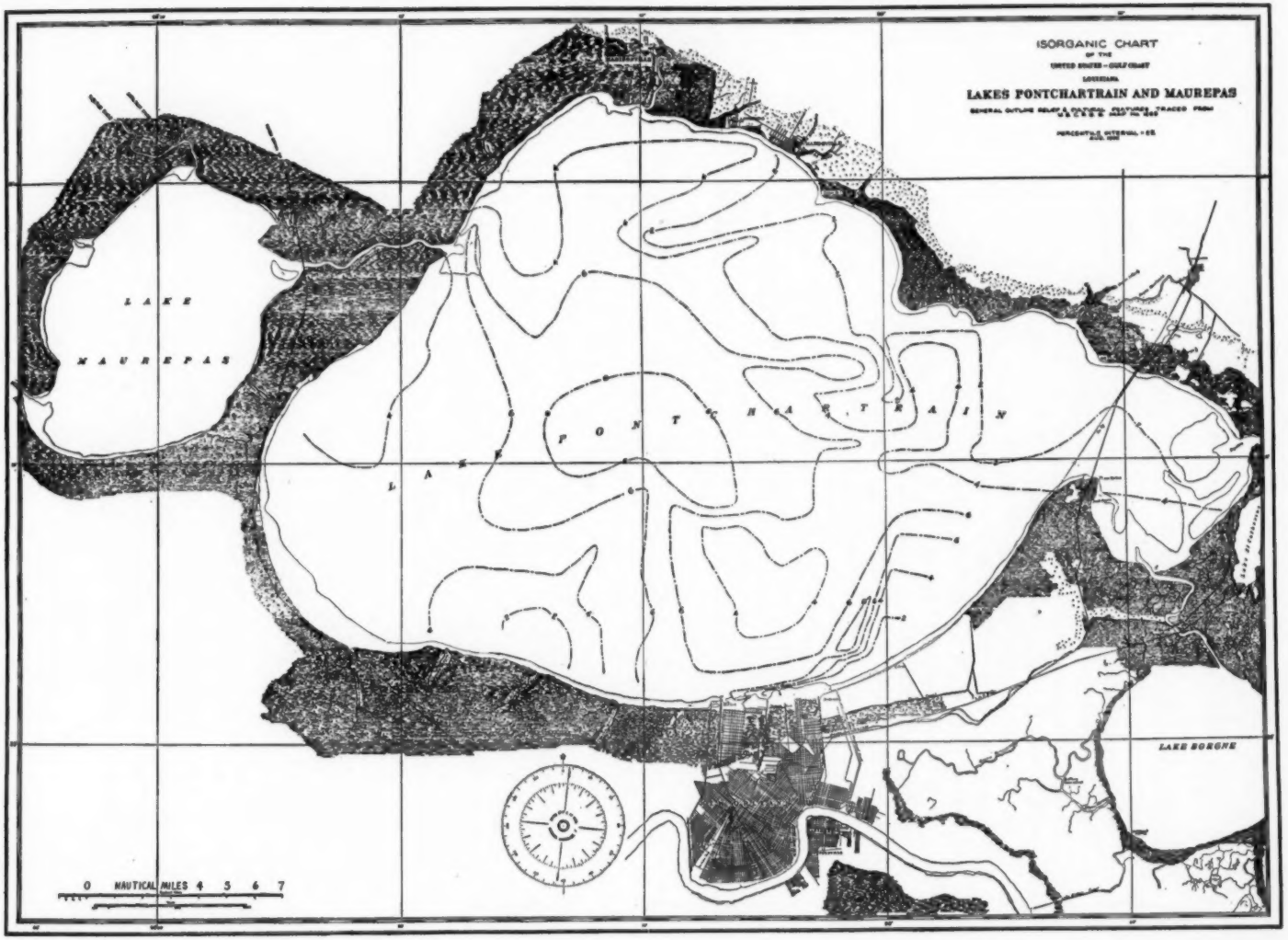

ISORGANIC CHART
LAKES PONTCHARTRAIN AND MAUREPAS
LAKE
MAUREPAS
PONTCHARTRAIN
LAKE
LAKE BORGNE
0 NAUTICAL MILES 4 5 6 7

FIG. 4

on the beaches, ridges, and steep slopes of the basin of the lake. Trask made a similar observation of the relationship between organic content and bottom configuration in his study of the Channel Islands Region of California.[8]

Relation of organic content to texture.—A comparison of the isorganic chart with the iso-textural chart shows a striking similarity between the iso-lines on the two charts. As the size of grain and summation of the mass of particles retained on 200-mesh and larger screens were important bases of separation of the sediments from the lake into various sub-classes, and furthermore, as there were marked variations in the organic content of the sub-classes shown in Table II, it becomes strikingly evident that a relationship exists between texture[9] and organic content. In general, high organic content is associated with low texture, and conversely low organic content implies high coarse-grain content.

STRATIGRAPHY

Above Cairo datum.—A comparison of those parts of the vertical sections above the Cairo datum plane (Fig. 5), taken along and parallel with the south shore of the lake between West End and Seabrook and, respectively, at distances of 2,500, 3,500, 4,500, and 6,500 feet from the shore, shows (1) that vertical and horizontal changes are greater in magnitude and number in the sediments near the present shore line than they are at distances farther out in the lake. This is in harmony with the normal distribution of lake sediments and implies that there is a greater and a more variable shifting of the materials near the shore than in the deeper water; (2) that the changes in the lateral and vertical distribution of the sediments become less and less as the deeper parts of the lake are approached until finally at the 6,500-foot line there appears to be a distinct arrangement of the sediments into layers; (3) that near the shore there is a distinct grouping of the sediments into lenses; (4) that east of the London Avenue Canal the sediments consist of soft fine-grained clays and silts whereas west of the canal they grade laterally into medium-grained sands; (5) that west of the London Avenue Canal the surficial silty sands grade lakeward into fine-grained soft silts.

Between Cairo datum and minus 10-foot Cairo datum.—A comparison

[8] P. D. Trask, "Sedimentation in the Channel Islands Region, California," Vol. 26, No. 1 (January–February, 1931), p. 37.

[9] The term "texture" as applied to the Lake Pontchartrain sediments refers to a percentage summation of the frequency distribution of all particles retained on a U. S. standard sieve series between and including the 200- and 20-mesh screens, expressed in terms of a known mass of the sediments dried at 110°C.

FIG. 4

of the vertical sections previously described between the Cairo datum[10] and a plane 10 feet below the Cairo datum reveals (1) that between these depths the sediments still have a lenticular distribution near the

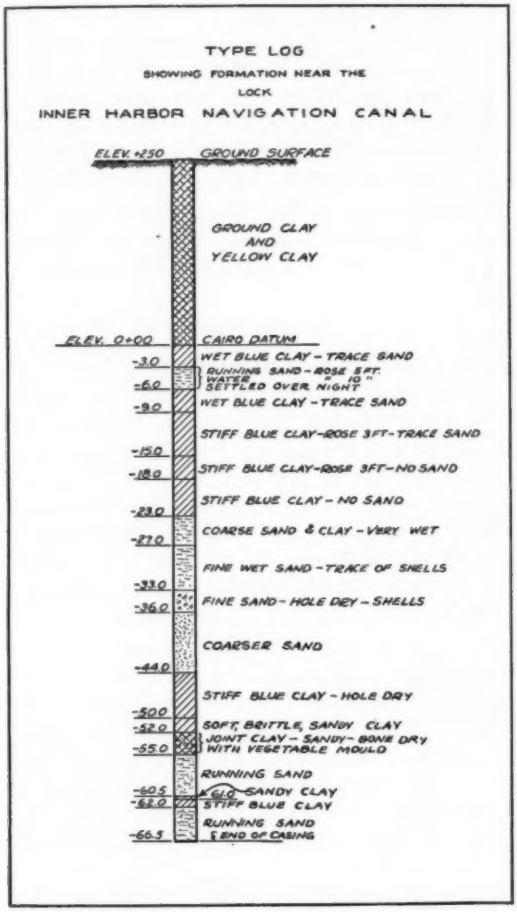


FIG. 5

shore line as in those parts of the sections above the Cairo datum plane. The lenticular grouping of the sediments below the Cairo datum, however, is not as irregular or as numerous as above this plane; (2) that in

[10] Zero Cairo datum is 20.43 feet below mean gulf level datum.

general the soft silts and clays from above have graded downward into more compact plastic clays; (3) that there is a distinct grouping of the sediments in the sections farther out in the lake into well defined layers; (4) that clays and clay-like materials predominate between these planes, implying that the water must have been deep and quiet there when the sediments were deposited and further implying that the shore line was farther inland at that time.

The areal distribution map of the horizontal section coinciding with the Cairo datum plane shows that clays and clay-like materials predominate in that part of the area between West End and the London Avenue Canal, although sands predominate near the shore line and clays farther out, west of the London Avenue Canal. There exists a *Rangia cuneata* shell bank near the mouth of the Orleans Canal.

Below minus 10-foot Cairo datum plane.—A comparison of the same vertical sections of that material below the minus 10-foot Cairo datum plane reveals (1) that a persistently thick sand stratum consisting of well sorted uniform quartz grains and containing the shells of marine mollusks extends under the entire area; (2) that the regularity in distribution of the sand as a stratum increases progressively with distances out into the lake; (3) that underlying the gray sand horizon occurs a distinctive green gumbo stratum; (4) that compacting seems to increase with depth; (5) that the sand stratum thins and finally disappears as the clay-like material thickens near the west part of the area.

TABLE III

PHYSICAL PROPERTIES OF LAKE PONTCHARTRAIN SEDIMENTS

Type of Material	*110°C. Volume Shrinkage* Per Cent*	*110°C. Loss in Weight* Per Cent*	*Porosity Per Cent*	*Apparent Specific Gravity*	*True Specific Gravity*	*110°C. Comparative Strength Pounds Per Square Inch*
Clay gels and soft silt	72.0	66.6	27.0	1.3	2.4	1,007
Gray clay	57.6	50.79	25.4	1.45	2.59	1,735
Green gumbo	23.15	24.45	22.8	2.0	2.52	920
Orange sandy clay	16.9	21.2	29.06	2.1	2.73	590
Gray sand		20.6		1.9	2.66	

* Wet-sample basis.

The areal distribution map showing the distribution of the sediments on a plane coinciding with the minus 10-foot Cairo datum plane reveals that most of the material in the entire area consists of sand and sand-like materials. Dredging operations in recent years probably explain the presence of clays and silts near the two navigation canals, New Basin Navigation Canal and the Industrial Canal.

In Table III are listed some of the physical properties of the more

important classes of sediments from Lake Pontchartrain. The sediments are arranged, with the exception of the sand, in a stratigraphic order, that is, the soft clays are the top sediments, and the orange sandy clays are the bottom sediments. The gray sand normally belongs above the green gumbos and below the gray clays. The decrease in the volumetric shrinkage, the decrease in the loss in weight, and the increase in apparent specific gravity of the material with depth further emphasize a previous statement that the sediments increase in compactness with depth.

MOLLUSCAN LIFE OF LAKE PONTCHARTRAIN

A survey of the marine mollusks from the lake and the Inner Harbor of the Industrial Canal (near the Mississippi River) at respective depths of about 30 feet and 47 feet below mean lake-level datum shows that most of them belong to tropical families living today on the strand or in enclosed bays and estuaries of the Gulf of Mexico. Their presence in the deep sand stratum implies that marine waters at that time covered much of the land area beyond the southern rim of the present lake. Whether these marine waters were a part of the waters of the ancient estuary into which the delta was extending itself, or whether they represent subsequent marine waters overlapping a subsiding delta is a moot question.

Regardless, however, of the origin of the marine bed, subsequent changes caused the marine waters to recede slowly from the land to the lake basin and thence through its tidal channels to the gulf. While in the lake they commingled with excess fresh waters brought down by streams from the near-by land. Thus the proportion of sea water was diminished with respect to the fresh water so that the lake water was freshened and slowly became brackish. A continuation of this same process has led almost to a complete freshening of the lake water. Marine organisms living in the waters while they were slowly changing in composition either adapted themselves to the changing conditions or migrated gulfward and were gradually replaced by brackish-water forms. *Ostrea* lived in abundance in the lake during the transitional stage from marine to brackish water. As they died their shells were later cast up onto the sand reefs to form an extensive *Ostrea* shell reef on the northern side of the lake. To the writer's knowledge no living oysters are found in the lake today. After the lake water became brackish, its molluscan life was dominated by the brackish-water clam, *Rangia cuneata*, which still lives in the clays and silts of the lake and whose shells have formed and are still forming the shell banks and the shell reefs.

The reported discovery of *Unio* and other fresh-water mollusks on the western side of the lake implies that if the lake cycle continues, as it has in the past, the brackish-water forms will gradually be replaced by fresh-water life.

MOLLUSKS FROM SAND STRATUM ON SOUTH SIDE OF LAKE, THE TOP OF WHICH IS APPROXIMATELY 30+FEET BELOW LAKE LEVEL

MARINE FORMS

Gastropoda

Fulgur pyrum Dillw.
Fulgur perversa Linn.
Olivia litterata Linn.
Strombus pugilis Linn.
Natica duplicata Say.
Terebra dislocata Say.
Purpura haemostoma Linn.
Purpura floridana
Crepidula aculeata Gmel.
Murex sp.?
Thais haemostoma Linn.
Cassis tuberosa Linn.

Pelecypoda

Pholas costata Linn.
Arca ponderosa Say.
Arca noae Linn.
Pinna seminuda Linn.
Pecten sp.?
Cardium magnum Born.
Venus mortoni
Venus mercenaria Linn.
Venus verrucosa
Dosinia discus Rve.
Tellina elegans Wood
Donax sp.?
Ostrea virginica Lister
Mactra sp.?

MOLLUSKS FROM INNER HARBOR OF INDUSTRIAL CANAL, 47 FEET BELOW GULF LEVEL

Strombus pugiles Linn.
Olivia litterata
Venus mercenaria Linn.
Dosinia discus Rve.
Cardium magnum Born

MOLLUSKS FROM SHELL BANK AND REEFS AS WELL AS LIVING FORMS IN THE LAKE

BRACKISH-WATER FORMS

Rangia cuneata
Ostrea sp.?
Mactra sp.?
Chama arcinella Linn.
Cyrena floridana
Cardium magnum Linn.

FRESH-WATER FORMS

**Unio* sp.?

* Reported to live in the muds on the west side of the lake.

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VOL. 23, NO 1 (JANUARY, 1939), PP. 24-44, 5 FIGS.

STRATIGRAPHIC FEATURES OF REEF RIDGE SHALE IN SOUTHERN CALIFORNIA[1]

STANLEY S. SIEGFUS[2]
Bakersfield, California

ABSTRACT

The Reef Ridge shale is restricted in this paper to a distinct lithologic unit essentially the same as the "caving blue shale" of Kettleman Hills and as such deserves recognition as a formation. From references made it is apparent that this was the original intention although the type locality, as described, included the upper member of Henny's previously described McLure (brown) shale formation. Field studies indicate that the formation as thus restricted is for the most part only about 300 feet in thickness and the upper and lower contacts are both gradational considering the definitions of the adjacent formations. Foraminiferal studies by R. M. Kleinpell, reported in this paper, have checked the original Miocene classification of Barbat and Johnson for at least the lower half of the formation at the type locality. The age of the upper part is not definitely known but it is presumed in general to be transitional between the Pliocene and Miocene as these terms are used in California at the present time following the general classification of B. L. Clark. The recognition of the formation in the other parts of the old San Joaquin Valley basin is considerably complicated by facies changes in the overlying beds. Because of the lack of suitable marker beds and fossils, in the Central Valley region, the writer suggests the arbitrary line at the top of the vaguely fissile silty shale as the upper contact of the formation in that area.

INTRODUCTION

The Reef Ridge shale formation was originally described by Barbat and Johnson in the *Journal of Paleontology*[3] in 1934. It is to be inferred from this description, that it was essentially the same as the "caving blue shale" of the Kettleman Hills oil field and similar gray shales of approximately the same stratigraphic horizon elsewhere in the southern part of the San Joaquin Valley. This use of the term was followed by Gester and Galloway[4] and has come into fairly common use.[5] But there are others, either familiar with the literature or with the geology of the area, who note that the type area along Reef Ridge as originally defined includes undoubted brown shale in its lower part even though as such it is not specifically mentioned in the original description. The fact that the type section, therefore, contains both brown and gray shale, while the beds commonly correlated with it are gray shale, has led to some confusion. It is the writer's purpose to discuss the stratigraphic relationships of the formation in the hope of establishing its correct place in California nomenclature.

[1] Manuscript received, September 10, 1938.

[2] Consulting geologist, 368 Haberfelde Building.

[3] W. F. Barbat and F. L. Johnson, "Stratigraphy and Foraminifera of the Reef Ridge Shale, Upper Miocene, California," *Jour. Pal.*, Vol. 8, No. 1 (1934), pp. 3–17.

[4] G. C. Gester and John Galloway, "Geology of Kettleman Hills Oil Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 10 (October, 1933), pp. 1174–80.

[5] See also *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., 1935), pp. 113–53.

The Reef Ridge shale was originally assigned to the Miocene from evidence obtained largely from well samples. More recently, members of the United States Geological Survey collected foraminifera from the middle portion of the formation at the type locality. These were classified by R. M. Kleinpell as being Upper Miocene[6] in age and essentially the same as Barbat and Johnson's original Reef Ridge fauna. This substantiates the view that the top of the Miocene is above the top of the brown (McLure) shale of the San Joaquin Valley, but because of the lack of fossils in the upper part of the formation and the gradational character of the beds, the Miocene-Pliocene contact in most places can not be accurately defined.

ACKNOWLEDGMENTS

The writer is especially indebted to R. M. Kleinpell and William F. Barbat for giving so freely of their time in assisting with the preparation of this report. To the Western States Gasoline Corporation, the writer is grateful for assistance while working in the Reef Ridge area. Thanks are also due R. D. Reed, A. R. May, Alex Clark, P. P. Goudkoff, Al Vitt and C. H. Montgomery for valuable help and criticisms.

DISTRIBUTION

The Reef Ridge shale was deposited in a basin somewhat smaller than the present San Joaquin Valley south of Fresno. On the west side of the valley, it crops out in the low hills between Coalinga and Maricopa (Fig. 1) including the type locality along Reef Ridge west of Kettleman Hills. Barbat and Johnson[7] noted its occurrence in the West Side Coalinga field and pointed out the correlation of the diatomite of the Chico Martinez Creek area with the Reef Ridge shale. Later work has led Barbat[8] to conclude that only the lower part of this diatomite correlates with the Reef Ridge shale and for this he suggests the term "Belridge diatomite" because of the difference in lithology. However, since this diatomite facies has not as yet been clearly differentiated from the typical Reef Ridge shale lithology into which it grades laterally, this diatomite and a similar one west of the Sunset Midway oil field will be grouped with the Reef Ridge shale for purposes of distribution.

At the south end of the valley east of Maricopa and on the east side of the valley, the Reef Ridge shale is found either to be completely

[6] The term Miocene is here used in the same sense as is common on the Pacific Coast at the present time, especially the classification followed by B. L. Clark, G. L. Richards, and others. See also the discussion by R. M. Kleinpell, pp. 38–40.

[7] *Op. cit.*, p. 8.

[8] W. F. Barbat, personal communication.

overlapped or to have graded into continental (Chanac) beds as has been graphically represented by Reed.[9] The time interval for this formation is probably represented by a hiatus in the San Emigdio Mountains and little is definitely known about the southernmost limits of its occurrence. From wells, it is known to extend some distance east of the Ten Section and Greeley oil fields, but it is not encountered within 6 miles of the city of Bakersfield. Along the eastern part of the valley, it probably extends east as far as Famosa, several miles east of Delano, and through the western part of Tulare County. Farther north and west the shale is found to grade into continental beds and is not found north of Fresno (Fig. 1).

The Reef Ridge shale probably reaches its maximum thickness in the vicinity of Elk Hills. In this area, Hoots and Herold[10] reported a thickness of approximately 2,700 feet exclusive of any underlying brown shales. A similar maximum thickness was reported by Barbat and Johnson[11] for Elk Hills. In general the thickness of the formation increases toward the center of the valley but there are some notable exceptions which will be discussed later.

REEF RIDGE SHALE FORMATION

The original description of the formation by Barbat and Johnson[12] is as follows.

> The Reef Ridge shale is typically exposed in a belt of degraded relief on the northeast side of Reef Ridge, Fresno and Kings counties, California, from Little Tar Canyon to Jasper Canyon. The belt is flanked on the southwest by the more resistant "McLure shale" and the ridge-forming Temblor formation. On the northeast the cuesta topography of the Etchegoin sands looms prominently in contrast. Outcroppings of the Reef Ridge shale are generally poor and infrequent. These evidences can be taken to imply that the formation is relatively non-resistant to erosion.
>
> The Reef Ridge shale of the type area is predominantly characterized by soft, blue (brown weathering) clay shale with minor beds of sandy shale. Toward the northwest end of the type belt there is an increase in sandiness and beds of brownish gray sandstone enter.

In referring to earlier work, Barbat and Johnson[13] point out that the Reef Ridge shale is the upper part of Arnold and Anderson's[14] Santa Margarita (?) which was described as follows.

[9] R. D. Reed, *Geology of California* (Amer. Assoc. Petrol. Geol., 1933), p. 242.

[10] H. W. Hoots and S. C. Herold, "Natural Gas Resources of California," *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., 1935), p. 145.

[11] *Op. cit.*, p. 9.

[12] *Op. cit.*, pp. 4 and 5.

[13] *Op. cit.*, p. 4.

[14] Ralph Arnold and Robert Anderson, "Preliminary Report on the Coalinga Oil District," *U. S. Geol. Survey Bull. 357* (1908), p. 38.

FIG. 1.—Reef Ridge shale basin (shaded area).

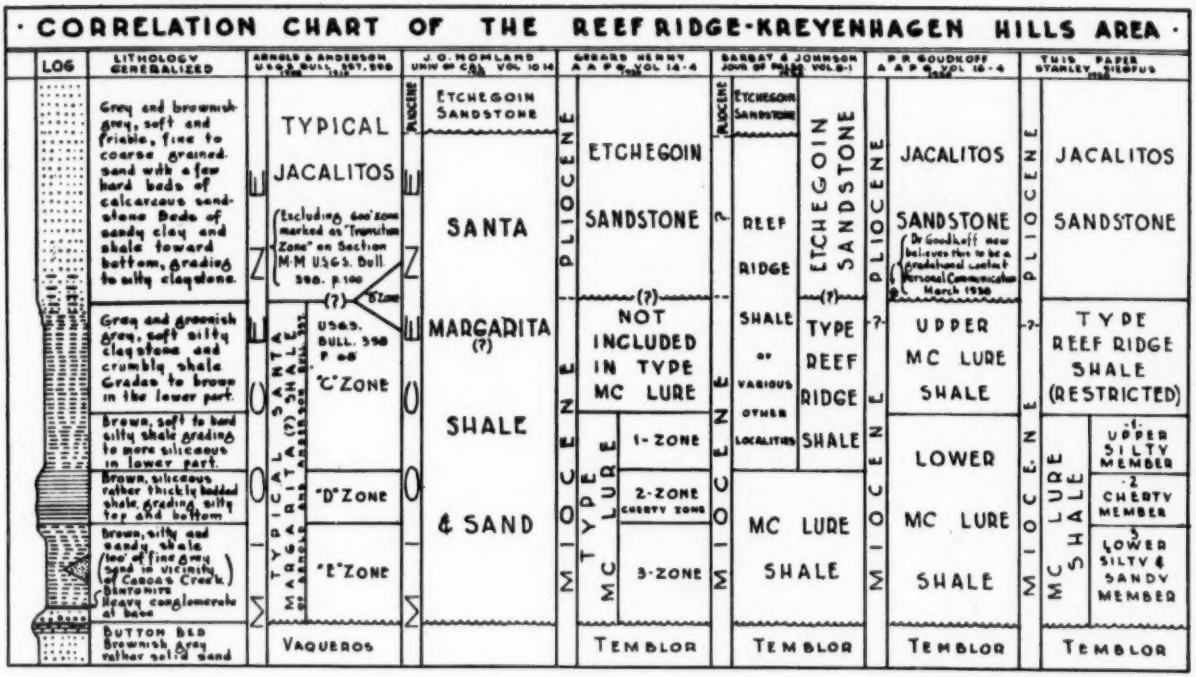
CORRELATION CHART OF THE REEF RIDGE-KREYENHAGEN HILLS AREA
LOG
LITHOLOGY GENERALIZED
Grey and brownish grey, soft and friable, fine to coarse grained sand with a few hard beds of calcareous sandstone Beds of sandy clay and shale toward bottom, grading to silty claystone.
Grey and greenish grey, soft silty claystone and crumbly shale Grades to brown in the lower part.
Brown, soft to hard silty shale grading to more siliceous in lower part.
Brown, siliceous rather thickly bedded shale grading silty top and bottom
brown, silty and sandy shale (100' of fine grey sand in vicinity of Cannons Creek) Diatomite Heavy conglomerate at base
BUTTON BED Brownish Grey rather soft sand
ARNOLD & ANDERSON U.S.G.S. BULL. 397, 1908
TYPICAL JACALITOS
(Excluding 600' zone marked as "Transition Zone" on Section M-M' U.S.G.S. Bull 396. p.100)
(?)
SLANT
TYPICAL SANTA MARGARITA (?) SHALE
U.S.G.S. BULL. 396 P 68
"C" ZONE
"D" ZONE
"E" ZONE
VAQUEROS
J. O. NOMLAND UNIV OF CAL VOL. 10-14
ETCHEGOIN SANDSTONE
SANTA MARGARITA (?) SHALE & SAND
GERARD HENNY A.A.P.G. VOL. 14-4
ETCHEGOIN SANDSTONE
(?)
NOT INCLUDED IN TYPE MC LURE
TYPE MC LURE
1-ZONE
2-ZONE CHERTY ZONE
3-ZONE
TEMBLOR
BARBAT & JOHNSON JOUR OF PALEO VOL 6-1
ETCHEGOIN SANDSTONE
REEF RIDGE SHALE or VARIOUS OTHER LOCALITIES
MC LURE SHALE
TEMBLOR
ETCHEGOIN SANDSTONE
(?)
TYPE REEF RIDGE SHALE
P. P. GOUDKOFF A.A.P.G. VOL. 10-4
JACALITOS SANDSTONE
(Dr Goudkoff now believes this to be a gradational contact Personal Communication March 1930)
UPPER MC LURE SHALE
LOWER MC LURE SHALE
TEMBLOR
THIS PAPER STANLEY SIEGFUS
JACALITOS SANDSTONE
TYPE REEF RIDGE SHALE (RESTRICTED)
MC LURE SHALE
1 UPPER SILTY MEMBER
2 CHERTY MEMBER
3 LOWER SILTY & SANDY MEMBER
TEMBLOR
PLIOCENE
MIOCENE

FIG. 2

It (Santa Margarita(?)) is divided into two main portions, the lower of which consists of harder, more siliceous and more thinly laminated purple and white shale, and the upper of softer, more argillaceous brownish shale. The lower portion is more conspicuous, constant and typical; the upper part is not so well exposed, is more variable in character and is not definitely separable from the soft sandstone and shale of the formation overlying.

The typical Santa Margarita (?) shale of Arnold and Anderson[15] was described for an area 3½ miles southeast of Big Tar Canyon or in the neighborhood of Sec. 27, T. 23 S., R. 17 E. The description is as follows.

	Feet
Soft, brownish, clay shale poorly exposed, grading above into fine sandy shale at the base of the Jacalitos formation and below into bluish purple siliceous shale with occasional hard more siliceous layers.	400
Hard siliceous, porcelaneous, thinly bedded shale, lavender colored, but weathering white, with prominent iron stain throughout along joints; breaking with angular and conchoidal fracture into elongated, sharp-edged pieces; interbedded with occasional soft laminae.	250
Fairly hard, purplish, siliceous and argillaceous shale, finely fractured into needle-like fragments with yellow calcareous concretionary lenses and interbedded porcelaneous layers; overlies the Vaqueros (Temblor).	400
Total	1,050

The two lower of these three zones . . . together make up the lower portion of the formation according to the division given above.

This relationship of the Santa Margarita (?) shale was represented graphically by Arnold and Anderson[16] and is reproduced in Figure 3.

In their report, Barbat and Johnson[17] described further details as follows.

The Reef Ridge shale forms a conspicuous unit in the Kettleman Hills well sections. In the early development of the North Dome of Kettleman Hills, the Reef Ridge shale was known as the "caving blue shale" because of the incapability of parts of it to stand in the walls of the wells. Core material shows it to be a brittle, silty, non-organic, blue shale with a very marked tendency to spall or exfoliate when lightly tapped. Thin beds of fine, hard gray sandstone occur in the upper half of the formation.

From this it is assumed that the "conspicuous unit" of the "caving blue shale" lithology was what the authors meant to segregate as the Reef Ridge shale formation.[18] In comparing the "caving blue shale" of the well sections with the outcrop along Reef Ridge, however, certain assumptions were made which in light of further work call for revision.

[15] *Op. cit.*, p. 38.

[16] Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District," *U. S. Geol. Survey Bull. 398* (1910), p. 68.

[17] *Op. cit.*, p. 7.

[18] Concurred in by Barbat, personal communication, 1936.

The lower half of the outcrop belt designated as the type locality of tbe Reef Ridge shale is made up chiefly of brown shale or brown siltstone generally harder than the typical overlying gray siltstone. This brown shale part was described by Arnold and Anderson, as already shown, and by Henny.[19] It can be seen at many places in the area. The contact between the two shale zones of different color is

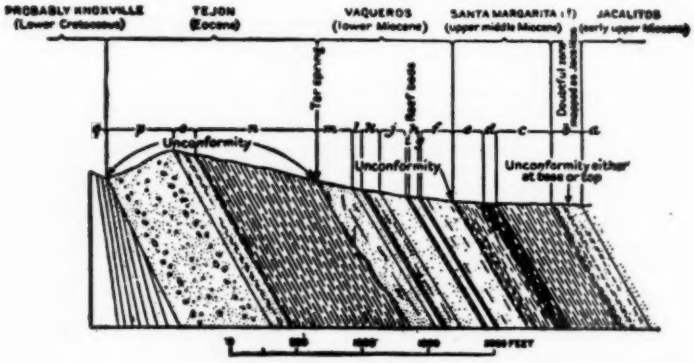

FIGURE 3. Section of the Santa Margarita (?), Vaqueros, and Tejon formations along the west side of Big Tar Canyon.

	Feet.
g. Gray and brown sand of the Jacalitos formation.	
b. Unfossiliferous brown sand and sandy clay, with occasional layers of hard yellowish-brown sandstone, apparently grading into the Jacalitos above and the Santa Margarita (?) below; of doubtful age, but mapped as Jacalitos	200
Santa Margarita (?).	
e. Soft blue shale at top, grading below into soft brown shale; some brown sand at the top	250
d. Prominent thinly bedded hard white and purplish siliceous shale	100
c. Hard shale similar to that above, grading below into thinly bedded chocolate-colored shale	200
	550
Vaqueros.	

FIG. 3.—Section and description of zones reproduced from *U. S. Geol. Survey Bull. 398*. Reef Ridge shale as described by Barbat and Johnson includes zone *c* and the lower part of zone *b*. The McLure shale as defined by Henny includes zones *e*, *d* and the lower part zone *c*. Reef Ridge shale as defined by this paper refers to the upper part of zone *c* and the lower part of zone *b*.

graditional at the few places where it can be seen. Some of the gulleys in Sec. 16, T. 23 S., R. 17 E., have exposures of this part of the section.

It is difficult to explain the relationship of a formation which might be a gray, soft and silty shale in the Kettleman Hills well sections and half gray shale and harder brown shale at the surface outcrop. Therefore, since the brown part of the formation at the outcrop is definitely

[19] Gerard Henny, "McLure Shale of the Coalinga Region, Fresno and Kings Counties, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 4 (April, 1930), p. 404.

a part of the McLure shale formation, as will be shown later, it is suggested by this paper that the Reef Ridge shall be restricted to refer only to the soft gray shales which make up only the upper part of what was originally defined as the Reef Ridge shale. With this revised description of the formation it is seen that the lower contact is gradational, and, as will be shown later, the upper contact is also gradational at most places. The formation in this sense would vary from 100 feet to hardly more than 400 feet in thickness except in a few places where it is believed to be nearly cut out by faulting.

McLURE SHALE FORMATION

Henny's[20] description of the type section of the McLure shale formation in Sec. 8, T. 24 S., R. 17 E., in McLure Valley is as follows.

"Etchegoin" (Pliocene)

	Feet
1. Dark brown clayey and silty shale apparently without micro-organisms	90
2. Hard siliceous brown shale with micro-organisms	320
3. Brown siliceous shale, softer and less resistant to erosion than shale No. 2. It contains limy concretions of dark gray color, the weathered surfaces of which are yellow. The top of this division is coarse silty shale. The base also is coarse silty shale, containing semi-rounded pebbles of the Franciscan (Cretaceous) and some white shale containing micro-organisms. These pebbles are not more than ½-inch in diameter	390
Cretaceous	
Total	800

Henny continues

These same divisions in the McLure shale exist also in Reef Ridge where the middle division is also more siliceous than the other part of the shale and forms a prominent feature.

This general relationship was also described by Arnold and Anderson, as has already been discussed, and hardly needs further verification for the area along Reef Ridge. But in describing the lower contact of the Reef Ridge shale, Barbat and Johnson[21] wrote, "The Reef Ridge rests on a series of brown (white weathering) siliceous and diatomaceous shales and thin limestone lentils," which is obviously Henny's No. 2 or middle division. In thus describing the lower contact they included within the Reef Ridge formation the upper or No. 1 zone of Henny's type McLure shale just described.

Henny[22] contends that he included the Reef Ridge shale within his McLure shale formation. A study of Henny's paper, however, shows that the gray part of the originally defined Reef Ridge shale escaped definite inclusion with the McLure. This part is not present at the

[20] *Op. cit.*, p. 404.

[21] *Op. cit.*, p. 5.

[22] Personal communication.

type locality of the McLure shale and no gray shale appears in the description. If this part of the original Reef Ridge shale were to be considered as part of the McLure shale, one would have to attach more significance to Henny's mention of Arnold and Anderson's Santa Margarita (?) than to his description because even in referring to Santa Margarita (?) he uses the word "brown." Barbat and Johnson[23] have pointed out a location (Section M-Mp.), where the Reef Ridge shale was not even regarded by Arnold and Anderson as belonging to the Santa Margarita (?).

FIG. 4.—Looking southeast toward Big Tar Canyon in Sec. 12, T. 23 S., R. 17 E., along the resistant, cherty shale zone of the McLure shale. The Reef Ridge shale is the dark, treeless belt on the left side of the saddle under *A*. Offset cherty zone seen through saddle.

The writer, therefore, concludes that since the upper gray shale of Barbat and Johnson's original type Reef Ridge shale, or the Reef shale as herein restricted, was not definitely included with the McLure shale, and because it is a separate and definite lithologic unit, it deserves a place in California nomenclature. The Reef Ridge shale formation as originally defined, however, has questionable standing considering the precedence of the McLure shale in the literature.

JACALITOS FORMATION[24]

It is hardly necessary here to review in detail the reasons for using this term for the beds overlying the Reef Ridge shale, instead of the

[23] *Op. cit.*, p. 4.

[24] The name, "Jacalitos formation" is used here instead of "Jacalitos sandstone" because this was the original term and while admittedly it is predominantly sandstone, the name implies that it also contains appreciable shale. See also *U. S. Geol. Survey Bull. 826*, "Names and Definitions of the Geologic Units of California" (1931).

term, Etchegoin, used by some writers. According to the original description of Arnold and Anderson,[25] the Jacalitos formation "may be roughly distinguished as that portion of the series between the shale of the Santa Margarita (?) below and the *major beds of blue sand* that are characteristic of the lower part of the formation above it (Etchegoin) throughout the district." The Jacalitos formation appears as a valid term in view of the work of the United States Geological Survey showing that the Etchegoin as originally defined does not include beds of the lower-lying Jacalitos formation.

The difficulty in mapping the upper contact of the Jacalitos has already been pointed out by Reed[26] who extended Arnold and Anderson's Jacalitos to include more than 1,000 feet of additional beds up to the *Mulinia* zone. Nomland[27] has described the similarity of the fauna of the Jacalitos to that of the Etchegoin and apparently for that reason abandoned use of the term Jacalitos formation. Because of this confusion, some prefer the term "Jacalitos-Etchegoin undifferentiated." Others contend that the Jacalitos sandstone has a certain stratigraphic significance which can not be altogether disregarded. From F. M. Anderson's first paper[28] it may be argued that he meant to include the Jacalitos sandstone as part of the Etchegoin formation. But in his later paper[29] he definitely separates the lower part of the Jacalitos from the Etchegoin, in the discussion of the Coalinga beds. This part of the section is discussed in some detail in connection with an ash bed 12–16 feet in thickness which is known to most workers in the area. Clark's conclusion[30] was

> that the Jacalitos should be recognized as a formation because: first, the distribution is different—the Jacalitos is present in certain areas where the typical Etchegoin is absent and vice versa; and second, the fauna, as a whole, is a fairly distinct unit.

The relationship of the Jacalitos and the Coalinga beds was shown in tabular form by Anderson and Pack.[31]

[25] *Op. cit.*, p. 40.

[26] *Op. cit.*, p. 226.

[27] J. O. Nomland, "The Etchegoin Pliocene of Middle California," *Univ. Calif. Geol. Series*, Vol. 10, No. 14 (1917), pp. 191–254.

[28] F. M. Anderson, "A Stratigraphic Study of the Mt. Diablo Range, California, *Calif. Acad. Sciences*, 3rd Ser., Vol. II (1905), No. 2.

[29] F. M. Anderson, "A Further Stratigraphic Study of the Mt. Diablo Range, California," *Calif. Acad. Sciences*, 4th Ser., Vol. III, pp. 24–25.

[30] B. L. Clark, "Tectonics of the Coast Ranges of Middle California," *Bull. Geol. Soc. America*, Vol. 41 (1930), p. 767.

[31] Robert Anderson and R. W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley, North of Coalinga, California," *U. S. Geol. Survey Bull. 603* (1915), p. 36.

Confusion in defining the upper contact of the Reef Ridge shale has resulted to some extent from the difference of opinion regarding the lower limit of the Jacalitos sandstone formation. Nomland[32] described an unconformity in Jasper Creek which he considered as the base of the Pliocene. He did not trace this unconformity to the southeast; therefore its true significance in this area is not known. Apparently it is lost a short distance southeast of the point of discovery because it could not be found farther southeast in the area. This unconformity is reported by Barbat and Johnson[33] to be at the top of Arnold and Anderson's "transition zone." From the writer's viewpoint, judging from its location and position in the section, it is definitely above any of the transition zones described in either of the previous authors' bulletins. Since the zone in question is non-fossiliferous and predominantly sand south of Jasper Creek and has more often been referred to the Jacalitos than to the Santa Margarita (?) or McLure, it appears to the writer that Arnold and Anderson's original lower Jacalitos contact, at the change from sand to shale, should stand in preference to Nomland's much higher and much more confusing "unconformable" contact (see correlation chart, Fig. 2).

The original statement of Arnold and Anderson[33a] reads:

> The Jacalitos in the Kreyenhagen Hills [which is also the type locality for the Reef Ridge shale] is probably unconformable with the Santa Margarita [Reef Ridge] below although the two formations appear conformable at the contact, the line between them being arbitrarily drawn where the beds that are predominantly shale (Santa Margarita) give place to sandy beds (Jacalitos).

Barbat and Johnson were apparently influenced by Nomland's work to conclude, "the Etchegoin [Jacalitos] sands rest with distinct unconformity upon the Reef Ridge." Because of errors of field mapping they included more sandy beds in the Reef Ridge shale near Jasper Creek than they did farther southeast. In the vicinity of Zapato Creek they list thicknesses of 400, 855, and 760 feet which apparently include some sandy beds, while southeast of Big Tar Canyon they report thicknesses of 395, 170, and 182 feet which apparently contain no sandy beds, judging from their statement that

> Toward the northwest end of the type belt there is an increase in sandiness and beds of brownish-gray sandstone enter. The thickness of the formation appears to be somewhat variable from several measured sections. This variation in thickness seems to be due largely to unconformity at the top of the formation. However, the mechanics of measuring are subject to some error, due to poor exposures and a general masking of the contact of the Reef Ridge shale and the "McLure shale" by debris of the latter formation.

[32] *Op. cit.*, p. 201.

[33] *Op. cit.*, p. 92.

[33a] Ralph Arnold and Robert Anderson, "Preliminary Report on the Coalinga Oil District," *U. S. Geol. Survey Bull. 357* (1908), p. 41.

From the writer's observation in the area, where the contact is drawn at the change from sand to shale as indicated by Arnold and Anderson, very few sandy beds can be seen within the formation. In the area between Jasper Canyon and Baby King Canyon, the writer traced beds low in the Jacalitos for considerable distances. These beds show a rather close parallelism with the Reef Ridge-Jacalitos contact as here described and indicate a general conformable relationship. In this area the general thickness of the Reef Ridge shale, as here restricted, would only be approximately 200 feet although there are a few places where it may possibly be as much as 300 feet. There are two places in the area just south of Zapato Creek, however, where the

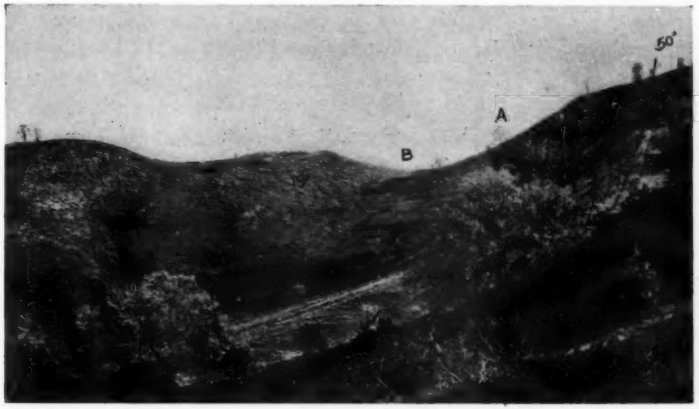

FIG. 5.—Near the N. ¼ corner, Sec. 25, T. 22 S., R. 15 E., looking southeast. Narrow section of Reef Ridge shale and upper part of McLure shale in saddle between *A–B*, thought to be due to faulting.

gray shale of the Reef Ridge shale is practically missing, probably due to strike faulting. In these places, as well as the sand-shale contacts already described, the sand is continuous above the contact and hence belongs to the Jacalitos sandstone by definition.

Apparently the Jacalitos sands in contact with the Temblor sandstone in the area between Jacalitos and Jasper Creek had led many workers to postulate a regional unconformity at this point, as for example Arnold and Anderson[34] who, in their later report, wrote:

> The Jacalitos formation in the Kreyenhagen field is unconformable with the shale mapped as the Santa Margarita(?) formation, as may be seen at the northwest end of Reef Ridge, where the shale becomes lost. Along the greater part of Reef Ridge, however, a definite appearance of an unconformity has not been found, . . .

[34] *Op. cit.*, p. 97.

That the apparent unconformity "at the northwest end of Reef Ridge" is due, to a considerable extent at least, to strike faulting has been shown by the writer's work in this area. Though the McLure shale is almost lost in this particular area, there is one small somewhat isolated exposure of it on the south side of Jacalitos Canyon in the north-central part of Sec. 11, T. 22 S., R. 14 E., which shows a definite dip to the south while the Jacalitos dips to the northeast and the Temblor stands nearly vertical. John Galloway,[35] working independently, also mapped a strike fault at this point and concluded from his accurate mapping of the area that about 1,100 feet of Jacalitos sandstone had been cut out. How much more faulting than this there might have been, he was not able to determine because of structural complications. Northwest of this area, according to Galloway, there are places where a definite unconformity can be seen at the base of the Jacalitos.

AGE OF THE REEF RIDGE SHALE

In his book the *Geology of California* Reed[36] pointed out the disagreement among workers as to where the top of the Miocene should be placed. At that time he accepted the boundary which put "most of the organic silicious rocks in the Miocene and the younger clastic deposits in the Pliocene," mentioning that there may be reason "that some of the upper silicious rocks which underlie the silts should be placed in the Pliocene." In the same publication before the term "Reef Ridge shale" was formally published by Barbat and Johnson, Reed[37] considered it as a transition zone between the Jacalitos and the Santa Margarita. Later, when the Reef Ridge shale paper was finally published classifying the formation as Miocene, this viewpoint required alteration. In their latest work, Reed and Hollister[38] wrote:

> It would seem, therefore, that the lower part, at least, of the formation is Upper Miocene, as the limit is now drawn in California, but the age of the upper part is not agreed upon by all interested parties.

In this connection they quoted Goudkoff[39] who wrote, in part,

> The microfauna in the upper part of the so-called "caving blue shale" or Reef Ridge formation shows that this part is much more closely related to the overlying Jacalitos than to the lower part of the "caving blue shale."

[35] Personal communication.

[36] R. D. Reed, *Geology of California*, Amer. Assoc. Petrol. Geol. (1933), pp. 207–208.

[37] *Op. cit.*, p. 236.

[38] R. D. Reed and Joseph S. Hollister, "Structural Evolution of Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 12 (December, 1936), p. 1609.

[39] Paul P. Goudkoff, "Subsurface Stratigraphy of Kettleman Hills Oil Field, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 4 (April, 1934), p. 473.

In another part of the same paper referred to, Goudkoff[40] wrote:

> The boundary between the Pliocene and the Miocene is not at the top of the so-called "caving blue," but is within the siltstone known by this name. Such a view finds support in the definitely Miocene aspect of the microfauna present in the lower part of the "caving blue," and in the Jacalitos (Pliocene) affinities of the microfauna of the upper part. This is particularly evident in the Petroleum Securities' Ladd No. 1, where a characteristically Jacalitos microfauna overlies siltstone which seems to represent the lowest beds of the "caving blue."

While much credit is due Goudkoff for the idea expressed in the foregoing statement, it should be pointed out that the type Jacalitos is predominantly a sandy formation and has furnished no foraminifera of distinctly chronological significance as far as is known. The shallow-water foraminifera referred to may be considered to have "Jacalitos affinities" only because they have been found elsewhere in association with Jacalitos mega-fossils. But most of these are also found in the Miocene so that in general these can not be relied upon as definitely denoting Pliocene age although further work may show some of the species to be of restricted range. Some mega-fossils, such as *Ficus ocoyana*, *Siliqua* cf. *patula*, and *Cryptomya californica*, which Barbat and Johnson originally reported from the Reef Ridge shale of Kettleman Hills, are likewise not diagnostic.

In the Chico Martinez Creek-Belridge area there are geological conditions which have led many workers to agree with Goudkoff's view. The upper punky, diatomite beds, roughly 900 feet thick, which comprise the upper part of what was referred to as "Maricopa shale" by English[41] in this area, were correlated with the Reef Ridge shale by Barbat and Johnson.[42] In the lower part of this interval Barbat and Johnson collected many of the original type species described in their paper. But in recent years, many Pliocene molluscan fossils have been collected from the upper part of this diatomite. Therefore, the idea has become rather common that in this area the upper part of the Reef Ridge shale is of Pliocene age.

Further work on the problem has led Barbat and others to believe that the Pliocene and Miocene beds in this area are separable even though at Chico Martinez Creek the section is well exposed and apparently conformable throughout. Barbat[43] believes that there is a sand (Calitroleum) separating the Miocene and Pliocene diatomites in

[40] *Op. cit.*, p. 474.

[41] W. A. English, "Geology and Petroleum Resources of Northwestern Kern County, California," *U. S. Geol. Survey Bull. 721* (1921).

[42] *Op. cit.*, p. 9.

[43] Personal communication dated April 1, 1937.

the Sunset-Midway area and he points to the work of W. D. Cortright to show there is a Pliocene fossiliferous sand above the Miocene diatomite at Chico Martinez Creek. The Pliocene diatomite, he states, is present at Gould Hills and in wells of the Belridge area with Pliocene mollusks, and that this diatomite "probably runs rather high in the Pliocene section (almost to the *Mulinia* zone)." Barbat further believes that there is an angular discordance between the Miocene and Pliocene diatomites and that the diatoms typical of each can be identified with a hand lens. Geologists interested in this problem will await with interest further publication of details describing these relationships.

The Miocene age classification of the Reef Ridge shale by Barbat and Johnson has recently been confirmed by R. M. Kleinpell for the middle and lower part of the formation of the type locality. Kleinpell's report is as follows.

In the course of field work carried on by the United States Geological Survey in the summer of 1931, a foraminiferal sample was collected by M. N. Bramlette, K. E. Lohman and R. M. Kleinpell, from an outcrop stratigraphically near the middle of the Reef Ridge shale. This outcrop[44] is located in a small gully on the west side of Big Tar Canyon in the south-central part of Section 7, Township 23 South, Range 17 East, southwestern Kings County, California. The results of the work referred to are included in a report on the geology of the Kettleman Hills in preparation by the Survey, and through permission of the Survey, a preliminary discussion of the Reef Ridge sample is possible here.

The following foraminifera were found in the sample under discussion:

Lagena (?) sp.	Rare
Nonionella miocenica Cushman	Rare
Buliminella curta Cushman (?)	Rare
Buliminella dubia Barbat and Johnson	Rare
Bulimina aff. *montereyana* Kleinpell	Rare
Bulimina cf. *ovata* d'Orbigny	Few
Virgulina californiensis grandis Cushman and Kleinpell	Common
Virgulina sp. (?)	Few
Bolivina brevior Cushman (?)	Rare
Bolivina obliqua Barbat and Johnson	Abundant
Bolivina seminuda foraminata R. E. and K. C. Stewart (?)	Rare
"*Bolivina* sp." Barbat and Johnson (?)	Rare
Bolivina vaughani Natland	Rare

In addition to the foraminifera, numerous large discoid diatoms were present and also a few doubtful radiolarians.

All the foraminifera were rather poorly preserved and rusty, and it was impossible to identify a number of them. Still others have been only doubt-

[44] This locality is approximately 2,000 feet west and 1,200 feet north of the southeast corner of Section 7. Much of the upper part of the formation showing the gradation to the overlying Jacalitos is fairly well exposed in this area, and immediately to the east a new road better exposes some of the beds. Unfortunately the lower part of the formation here remains covered by overburden, so there appears to be no satisfactory locality for a type section.

fully identified. The specifically unidentified specimens referred to *Virgulina* probably represent more than one species; most of them are fragmentary and are apparently *Virgulina californiensis californiensis* or perhaps in part immature specimens of the variety *grandis*, but there are also one or two very different smaller and more slender forms which suggest *Virgulina subplana* Barbat and Johnson. In spite of relatively poor preservation it is clear that the assemblage represents essentially the same foraminiferal fauna which is present in subsurface sections of the lower and middle Reef Ridge ("caving blue") shale of Kettleman Hills as recorded by Barbat and Johnson.[45]

The foraminifera listed above appear to represent a fauna characteristic of the neritic zone, suggesting deposition of the containing shale on the continental shelf at a depth of perhaps more than 30 fathoms but not much greater than 100 fathoms.

The recorded stratigraphic ranges of several of the species present clearly point to an Upper Miocene age of the fauna, as the term, Miocene, is at present used in West Coast stratigraphy. Barbat and Johnson arrived at a similar conclusion concerning the age of the similar subsurface assemblages from the nearby oilfields. The species, *sensu stricto*, of *Buliminella curta*, *Buliminella dubia*, *Bulimina montereyana*, *Virgulina californiensis grandis*, *Bolivina brevior* and "*Bolivina* sp." Barbat and Johnson are at present not definitely recorded from beds as young as the California "Lower Pliocene," although forms closely related to some of these are found in Pliocene and even Recent deposits. On the other hand, all the Bolivinas except *B. brevior* are known only from the upper part of the "Upper Miocene," and the assemblage may therefore be, with considerable assurance, referred to the Delmontian Stage, a correlation which is in accord with the known stratigraphic relations of the Reef Ridge shale with the higher and lower fossiliferous beds of the Jacalitos and McLure formations respectively.

Bolivina obliqua appears to be the most stratigraphically restricted species in the assemblage, as a consequence of which its name has in fact been applied to the lowermost Zone in the Delmontian Stage.[46] The presence of this species in the outcropping middle Reef Ridge shale, in the lower and middle Reef Ridge shale of the Kettleman Hills oilfield, at a depth of 1995 feet to 2000 feet in the Standard Oil Company Piedmont well in the Salinas Valley and in the diatomaceous shales of Hoots' unit 18 of the Upper Modelo formation near Girard in the Santa Monica Mountains,[47] is at present considered as evidence strongly favoring the zonal correlation of the containing shale at these various localities. A similar assemblage has recently been reported from the lower Sisquoc formation of the Santa Maria Valley.[48] Moreover an assemblage from a depth of 2215 feet to 2218 feet in the same Piedmont well

[45] W. F. Barbat and Floyd L. Johnson, "Stratigraphy and Foraminifera of the Reef Ridge Shale, Upper Miocene, California," *Jour. Pal.*, Vol. 8, No. 1 (March, 1934), pp. 3–17, Pl. 1.

[46] R. M. Kleinpell, unpublished manuscript.

[47] W. D. Rankin, in H. W. Hoots, "Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California," *U. S. Geol. Survey Prof. Paper 165-C* (1931), p. 113.

[48] Charles R. Canfield, "Subsurface Stratigraphy of Santa Maria Valley Oil Field and Adjacent Parts of Santa Maria Valley, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 1 (January, 1939), pp. 45–81.

may be correlated with the uppermost Mohnian beds of both southern California and the Monterey Bay area through the presence of *Bolivina goudkoffi* and of *Nonion montereyanum montereyanum* and *Nonion montereyanum carmeloensis*. Thus it is strongly suggested that the formaminiferal lower and middle Reef Ridge shale comprises a correlative of the lower and middle type Delmontian; i.e., Member 2 and the lower part of Member 1 of the typical Monterey as subdivided by Galliher.[49] This suggestion is strengthened by the presence of *Astrodapsis jacalitosensis* in the sandstones which conformably overlie both the typical Reef Ridge shale and the type Delmontian which corresponds to the uppermost typical Monterey shale. This comparison of the Reef Ridge and Monterey areas yields further, although indirect, evidence as to the stratigraphic position of the Reef Ridge shale foraminifera with respect to the sequence of the faunas of larger invertebrates. The lower type Delmontian is, among other characters, distinguished by the presence of *Nonion schencki*, a species which at present appears to be as stratigraphically restricted throughout the central coast ranges as is *Bolivina obliqua*, and which in fact appears to be restricted to the same stratigraphic interval. *Nonion schencki* has been found by Richards in the Nipomo quadrangle associated with an assemblage otherwise comparable with that of the lower and middle type Delmontian, and this foraminiferal assemblage occurs in the upper part of a shale body in the lower part of which are lenticular sand bodies carrying *Astrodapsis tumidus*.[50] The shale body is in turn conformably overlain by a sandstone reef carrying *Astrodapsis salinasensis*, a few hundred feet above which there is another invertebrate fauna which Richards considers the correlative of that in the typical Jacalitos Formation.

In addition to *Bolivina obliqua*, *Bolivina vaughani* may also be stratigraphically more or less restricted,[50a] but adequate stratigraphic control over the range of this distinctive form is at present still lacking. The type is from the Recent. It is present in the subsurface Reef Ridge shale of Kettleman Hills as well as in outcrop, and it is also known to occur in subsurface sections in the south-central San Joaquin Valley where it occurs in the few hundred feet of dark colored and somewhat silty mudstones and shales immediately overlying sandstones which are the approximate equivalents of the producing sands of the Ten Section and Greeley oilfields.

Because no diagnostic fossils have as yet been found at the type locality above the samples reported on by Kleinpell, the age of the upper part of the formation is not definitely known. From Kleinpell's statement that "it is strongly suggested that the foraminiferal lower and middle Reef Ridge shale comprise a correlative of the lower and middle type Delmontian," it appears that the upper part might well

[49] E. Wayne Galliher, "Stratigraphic Position of the Monterey Formation," *Stanford Univ. Micropal. Bull.*, Vol. 2, No. 4 (March, 1931), pp. 71–74.

[50] George L. Richards, Jr., "Revision of Some California Species of Astrodapsis," *Trans. San Diego Soc. Natural History*, Vol. 8, No. 9 (1935), pp. 59–66, 1 pl.

[50a] Since writing this passage, additional evidence bearing upon the stratigraphic range of *Bolivina vaughani* has come to light, indicating its definite occurrence at horizons lower than those here termed Upper Miocene. It has recently been found in subsurface sections of the central San Joaquin Valley associated with such species as *Valvulineria californica*. R.M.K.

be the correlative of the upper Delmontian. Since the upper Delmontian is the first sequence below known Pliocene, the inference is rather strong that the top of the Reef Ridge shale may mark the top of the Miocene at least at the type locality.

To the east and toward the center of the old Reef Ridge shale basin the beds of the "caving blue shale" type of lithology increase in thickness. Apparently younger beds enter this lithologic unit going basinward. The problem, therefore, with the lack of fossils and the lithological gradation into the overlying beds, resolves itself into one of formational recognition. The principles of stratigraphic nomenclature which deal with this problem allow such a wide range of opinion under the conditions that it is hardly possible here to discuss all of its phases. Rules and suggestions dealing with stratigraphic nomenclature in general are to be found in the 24th Annual Report of the United States Geological Survey, reports by Stanton,[51] Hedberg,[52] Eaton,[53] and others, as well as the report of the Committee on the Classification and Nomenclature of Rock Units[54] published in 1933.

According to what nomenclatural interpretation is followed the Reef Ridge shale may be referred to any one of the following classes.

1. All of the formation may be Miocene at the type locality and include some Lower Pliocene beds in areas basinward (see Fig. 1.)

2. The upper part of the formation may questionably be referred to the Pliocene at the type locality and the formation considered both Miocene and Pliocene elsewhere.

3. The formation as a whole both at the type locality and elsewhere may be considered to be of Miocene age.

Because of its lithology, stratigraphic association, and, to a lesser extent, its contained fossils,[55] the Reef Ridge shale can be recognized throughout a large part of the south-central San Joaquin Valley. In much of this region the sediments are so silty and clayey, that from general lithological character the formation may appear to be of considerable thickness. In some places a similar lithology reaches up nearly to the *Mulinia* zone or well up into definitely Pliocene beds.

[51] T. W. Stanton, "Stratigraphic Names," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), pp. 1070–79.

[52] H. D. Hedberg, "Stratigraphy of Rio Querecual Section of Northeast Venezuela," *Geol. Soc. America*, Vol. 48 (1937), pp. 1971–2024.

[53] J. E. Eaton, "Standards in Correlation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 4 (April, 1931), pp. 367–85.

[54] "Classification and Nomenclature of Rock Units," *Bull. Geol. Soc. America* (1933), No. 44, pp. 423–59.

[55] These features in order named being those most essential in recognition of a formation.

These upper beds containing Jacalitos or Pliocene fossils according to one interpretation, could not be Reef Ridge shale because of such contained fossils. On the other hand, there is no absolute assurance but that at some future time Pliocene fossils may be found in the upper part of the formation at the type locality. Therefore, since the beds under question are, in a sense, the gradational zone from one formation to the other, the writer feels justified in setting an arbitrary line of separation in this area as suggested by the *Rules of Stratigraphic Nomenclature* for 1933.

Well cores from the same range as the typical Reef Ridge shale micro-fauna in the Central Valley region have a somewhat distinctive lithology compared with even the softer siltstone beds higher in the section. These lower cores show a vague fissility, are generally somewhat harder and more commonly of a darker gray color while the higher ones have more of a conchoidal fracture and are generally somewhat greenish although the difference in color is not as essential in differentiation as the fissility. This change of lithology has already been used by the majority of geologists working in the area as the top of the Reef Ridge shale but it has not been consistently followed where there is a marked difference in thickness. Whether the top of this vaguely fissile shale is the time equivalent of the top of the shale at the type locality or any other locality it is difficult to say. In all probability it is not the *exact* time equivalent at the various places where it is encountered but in most cases this difference is not great or especially consequential. Therefore, for want of a more accurate line of separation in this transitional zone, the top of this vaguely fissile shale is suggested as the top of the Reef Ridge shale in the subsurface sections of the southern part of the San Joaquin Valley.

The lithologic change just described comes in that part of the section where there is little else to use for identification. In some localities in the central part of the Southern San Joaquin Valley, the beds below the lowest Jacalitos mega-fossils are barren of fossils in the same way that the upper part of type Reef Ridge shale is lacking in fossils. Elsewhere, large numbers of the foraminifer *Buliminella elegantissima* (d'Orbigny) occur in this range above the typical Reef Ridge micro-fauna. To this part of the section Barbat[56] referred the name "*Buliminella elegantissima* zone" in a paper delivered before the Society of Economic Paleontologists and Mineralogists at Los Angeles on March 18, 1937. This zone was regarded by him as being of Plio-

[56] W. F. Barbat, "The Post Miocene of the Maricopa Basin," unpublished paper (also personal communication). See program, 22nd Annual Meeting, Amer. Assoc. Petrol. Geol., Los Angeles (1937).

cene age and above the Reef Ridge shale, although originally it was considered part of the Reef Ridge shale. In the upper part of this zone he reported *Ficus ocoyana, Siliqua* cf. *patula* and *Cryptomya californica*, although these fossils were also reported from the Reef Ridge shale of the Kettleman Hills in the original paper. Barbat at the Los Angeles meeting described a "tectonic break" at the end of Miocene time which also marked the top of the Reef Ridge shale. The *Buliminella elegantissima* floods were considered Lower Pliocene and above the "tectonic break," which Barbat described as being widespread and important from a structural standpoint. No doubt at several places on the border of the San Joaquin Valley basin (or Maricopa basin of Barbat) this "break" is easily seen but in the center of the basin, where the sedimentation has been continuous, there is no sharp line separating the Miocene and Pliocene.

A survey of all of the information bearing on the so-called "*Buliminella elegantissima* zone" is hardly possible here. In local areas it appears to be useful for correlation in spite of the fact that the species has a range of occurrence extending down into the Lower Miocene. In other areas its position is more uncertain and irregular. One such example is the Shell Oil Company "Williams" well No. 1 on Semitropic Ridge in the center of the valley. This well, which was drilled to 9,700 feet, is regarded by most geologists to have penetrated a short distance into the hard brown (McLure) Miocene shale. Yet in this well there is no typical Reef Ridge shale fauna and the *Buliminella elegantissima* zone was found within 100 feet of the bottom of the hole. Sandy beds were cored down to about 9,500 feet, and from this and other features the Reef Ridge shale is considered to be hardly more than 150 feet thick in this well while in the Seaboard Oil Co. K.C. well No. 1 near Wasco, 8 miles to the east, there is a thickness of more than 1,000 feet of Reef Ridge shale and the *Buliminella elegantissima* zone was found about 900 feet above the top of the brown Miocene shale. Such examples as these cast doubt on the value of this zone for purposes of general correlation.

SUMMARY

1. It is apparent from the references consulted that the Reef Ridge shale was intended to be a distinct lithologic unit, essentially the same as the "caving blue shale" of the Kettleman Hills well sections.

2. Field studies by the writer indicated the necessity of restricting the formation at its type locality to exclude the brown shales and silts in the lower part of the originally defined Reef Ridge shale because that part of the section had been previously included in the McLure shale by Henny. The formation thus restricted corresponds more nearly with the "caving blue shale" of Kettleman Hills and for the most part it is only about 300 feet in thickness.

3. Field studies also indicated that the upper and lower contacts of the formation are gradational at the type locality, in view of the original definitions of the adjacent formations.

4. On the basis of R. M. Kleinpell's findings and the previous work of Barbat and Johnson, the Reef Ridge shale is considered to be Upper Miocene in the middle and lower part. The age of the upper part is not definitely known but is assumed in general to be transitional between the Pliocene and Miocene as these terms are used in California at the present time following the general classification of B. L. Clark.

5. Because of the nature of the sedimentation and lack of diagnostic fossils the upper contact of the formation in many places in the central part of the southern San Joaquin Valley is indefinite and uncertain. The foraminifera just above the typical Reef Ridge fauna are of the shallow-water type which are not dependable for regional correlation. As there are no other means for recognition, lithology alone must be relied upon. Therefore, in this connection the writer suggests that the arbitrary line at the top of the vaguely fissile silty gray shale be used as the upper contact of the formation in this area. The base of the formation there, as well as in other areas, is marked by the first appearance of the brown, harder, and more fissile shale. Though contacts so drawn are not necessarily the exact time equivalents of similar contacts in the same or near-by areas, they are believed to be as nearly contemporaneous as can be designated under the conditions.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 1 (JANUARY, 1939), PP. 45-81, 8 FIGS.

SUBSURFACE STRATIGRAPHY OF SANTA MARIA VALLEY OIL FIELD AND ADJACENT PARTS OF SANTA MARIA VALLEY, CALIFORNIA[1]

CHARLES REITER CANFIELD[2]
Orcutt, California

ABSTRACT

The Santa Maria Valley oil field is located in the northwestern corner of Santa Barbara County, California. The stratigraphic section penetrated in wells drilled in the field comprises rocks of Cretaceous (?), Middle to Upper Miocene, Lower to Upper Pliocene, Pleistocene, and Recent age. The Miocene is the oil-producing portion of the section. It consists of the Upper Miocene Santa Margarita(?) formation and the Middle Miocene Monterey formation. The Monterey can be divided into seven easily recognizable lithologic and faunal units: namely, (1) "Arenaceous" zone (top), (2) Cherty zone, (3) Bentonitic-Brown zone, (4) Buff and Brown zone, (5) Dark Brown zone, (6) Oil Sand zone, and (7) Siltstone and Shell zone (bottom). The Cherty zone and Oil Sand zone are the main producing parts of the Monterey, although some production is derived from the Santa Margarita(?), "Arenaceous" zone, and Dark Brown zone.

The Santa Maria Valley is a structural syncline trending generally east and west. The oil field is located on the north homoclinal flank of the syncline. The Monterey shales and sands lap northward over an older basement rock, called "Franciscan." The Monterey is moderately folded and faulted, and partly buttresses against the overlying gently dipping Sisquoc formation, which is in turn overlain by the Foxen, Paso Robles, and alluvium and stream gravel formations. In deeper parts of the valley, the so-called Santa Margarita(?) intervenes between the Monterey and Sisquoc.

Potential production of individual wells varies from 25 to more than 5,000 barrels per day of 12°–17.5°-gravity crude.

INTRODUCTION

LOCATION

The Santa Maria Valley comprises about 130 square miles of fertile flat lands and rolling country, lying in the northwestern corner of Santa Barbara and the southwestern corner of San Luis Obispo counties, California (Fig. 1). From the Pacific Ocean, on the west, the valley extends inland for about 20 miles in a southeasterly direction, diminishing from a maximum width of 8 miles until it merges with the narrow Sisquoc Canyon, on the east. It lies between the elevated Nipomo Mesa dune-sand area and the moderately folded San Rafael Mountains on the north, and the gently folded Casmalia Hills and Solomon Hills on the south. The floor of the valley varies from 100 to 400 feet in elevation. The extreme western part and most of the southern half of the valley are covered with dune-sand deposits, with elevations varying up to 750 feet.

The Santa Maria Valley oil field lies near the center of the valley. Developments to the present time show the field to be more than 7

[1] Delivered before the Paleontology and Mineralogy Division of the Association at Los Angeles, March 18, 1937. Manuscript received, September 12, 1938.

[2] Division paleontologist, Union Oil Company of California.

miles long, east and west, and 1–2 miles wide, north and south. There are approximately 5,000 acres of proved, or semi-proved, oil land in the field at the present time.

HISTORY OF DEVELOPMENT

Previous to the discovery of the Santa Maria Valley field, there were seven oil fields in the Santa Maria district, all within 18 miles south and southeast of the town of Santa Maria. These were the Cas-

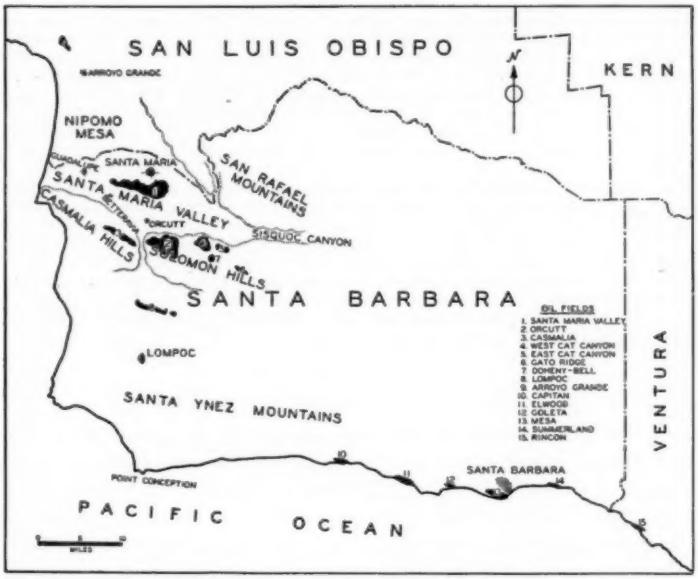

FIG. 1.—Map showing location of oil fields in Santa Maria district and on Santa Barbara coast.

malia, Orcutt, Lompoc, West Cat Canyon, East Cat Canyon, Doheny-Bell, and Gato Ridge fields (Fig. 1). There have been several oil booms in the area, the greatest activity occurring at the time of the World War. Some of the first oil produced in California was mined from the asphalt-saturated sands in the Santa Maria area. Oil has been produced from the district for 40 years.

Aside from the mining of asphalt in the eastern end of the valley, at Fugler's point, no attempt was made to produce oil from the Santa Maria Valley proper until 1912, when the Bradley Canyon Oil Company drilled a shallow hole to 1,573 feet. This well was abandoned be-

fore reaching the Foxen formation. In January, 1913, the St. Helens Petroleum Company began a well just south of Fugler's Point, apparently to tap the source of the oil at the point. By April, 1915, this well had been drilled to a depth of 5,312 feet. The well penetrated about 3,500 feet of Monterey formation, and produced a small quantity of extremely viscous tar. From 1913 to 1924, only two other attempts were made to find oil in the valley. In 1914, the Summit Oil Company drilled a hole to 3,150 feet at the extreme eastern end of the valley. In 1919, the Petroleum Midway Company drilled a hole to 3,434 feet on the old Paderewski Ranch in the middle of the valley. Neither of these wells drilled through the Foxen and neither produced any oil. In 1924 and 1925, the General Petroleum Corporation drilled three core holes in the central eastern part of the valley. The deepest of these reached a depth of 2,397 feet, but did not penetrate any of the present oil-producing formations. In 1928 and 1929, the Shell Company drilled six core holes for geological information in the region around the small town of Betteravia, in the central part of the valley. The deepest hole penetrated to 3,035 feet, but did not pass through the Foxen formation.

Beginning in 1929, and continuing until 1933, a considerable number of core holes and wildcats were drilled in the Santa Maria Valley. The Wildcat and Royalty Company started a well in the southwestern part of the valley in 1929. This well, later taken over by the Sovereign Oil Company, was taken to a depth of 5,460 feet, without encountering any Miocene. It was abandoned in 1931, after an unsuccessful attempt to produce oil. In 1929, the System Oil Company started a well (Bradley No. 1) just south of the present field. This well was finished in 1930 to a depth of 5,267 feet, just into the Santa Margarita(?) formation. It produced about 25 barrels of 14.4°-gravity oil. The well was abandoned in 1933. In 1930, the System started another well (Norswing 1), which was later taken over by O. C. Fields. This well, about two miles southeast of the first hole, was carried down to 5,568 feet, and produced a little very heavy oil. From 1930 to 1932, almost offsetting the O. C. Fields' well, the Western Gulf Oil Company drilled a hole to 10,299 feet—the deepest hole in the world up to that time. The well penetrated considerable Monterey, but never reached the basement. It had several oil showings, but was finally abandoned. In 1930, the Keystone and Earl Petroleum companies drilled a wildcat to 4,627 feet on the Paderewski Ranch, just north and east of the original Petroleum Midway hole. This well was abandoned before it reached the base of the Foxen. The most systemmatic exploration for oil during this time was that conducted by the Superior Oil Company.

In 1932, this company drilled seventeen core holes along the northern border of the valley in an effort to discover whether overlap and buttressing of the overlying formations against the underlying basement rock existed in that part of the valley. Apparently satisfied that such conditions prevailed, the company drilled a deeper hole on the Edna Bradley lease about a mile southeast of the town of Santa Maria. The hole was carried to a depth of 2,020 feet. It penetrated several hundred feet of Monterey, but was never tested.

In 1934, the Union Oil Company of California, for a long time the largest single operator in the Santa Maria district, actively entered the Santa Maria Valley in search of oil. In February, 1934, this company drilled Rice No. 1, which proved to be a dry hole. Moretti No. 1, Union's second attempt, begun in June, was completed at a depth of 2,389 feet as a small producer on July 15, 1934. This was the discovery well of the Santa Maria Valley oil field. The completion of a 50-barrel well with 16°-gravity oil did not startle the California oil fraternity, and the next couple of dry, or almost dry, holes drilled by Union were not encouraging. However, on March 31, 1936, when the Union Oil Company brought in Adam No. 1 for 2,376 barrels of 16.4°-gravity oil, the presence of a major new oil field was definitely established. Leasing activity began with a rush, and continued with varying vigor up to January, 1938.

The R. R. Bush-Hancock Oil Company combination and A. N. Macrate, independent from Long Beach, followed closely in Union's footsteps with producing wells. Since the completion of the discovery well, more than 135 wells have been drilled in the Santa Maria Valley, and of these only about ten have been dry holes. The present distribution of wells is shown in Figure 2.

LIMITS OF FIELD

The northern limit of the present drilled part of the Santa Maria Valley oil field has been partly defined by a half-dozen dry holes which pass directly into the basement rock without encountering any Monterey. The northern limit will be along a line at the edge of the Monterey where it pinches out against the basement rock. This line, approximately shown in Figure 2, is somewhat irregular, but may be said to be an east-west line running along the southern boundary of the town of Santa Maria, with two large curves to the south, one in Sections 22 and 23, and another northeast of the town of Betteravia. The southern limit of the field is unknown at the present time, although three or four wells drilled on the south have encountered water. While these wells produce considerable oil, it is probable that

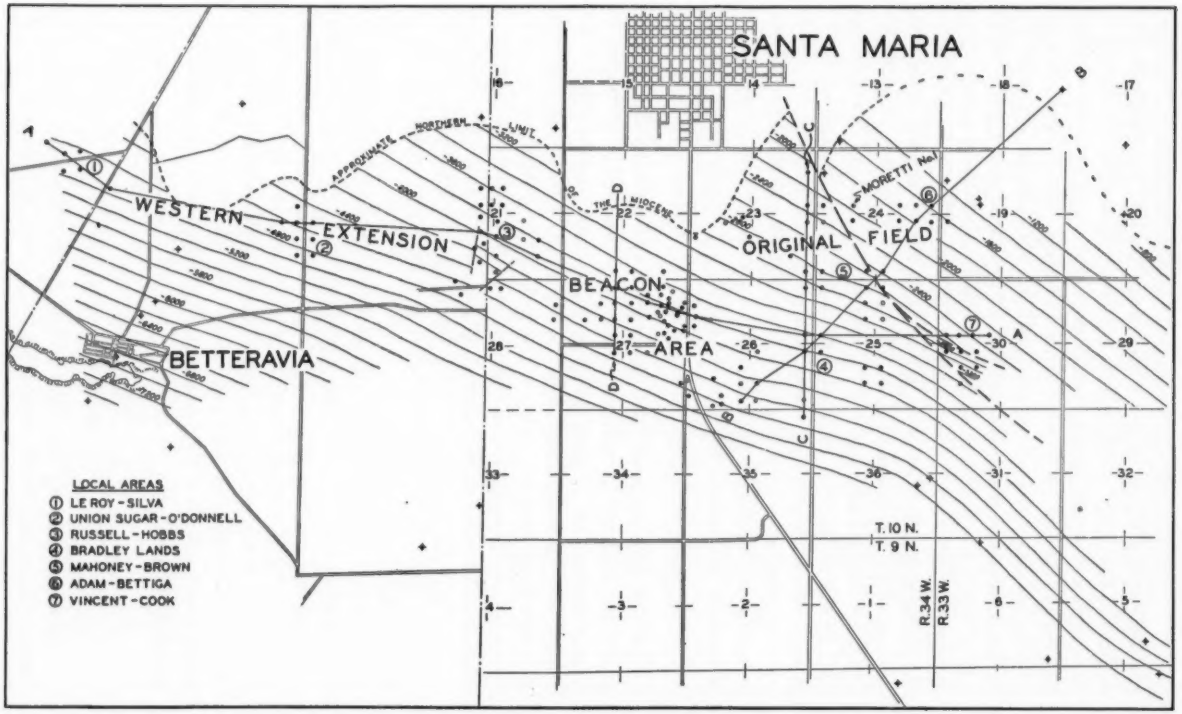

FIG. 2.—Map of Santa Maria Valley oil field showing location of wells, subsurface contours on top of Miocene, and location of cross sections.

the limit of the field is not very far beyond present development. It is estimated that edge water will be encountered in wells which top the Monterey below the minus 5,000-foot contour, and that the southern limit of the field will not be far beyond this line. The eastern boundary of the field has not been determined, but it is doubtful whether the field will continue much beyond the present development. In the first half of 1937, the field was extended westward about 2½ miles, by the completion of Union Oil Company's O'Donnell No. 1. In October, of the same year, the field was extended about 2½ miles farther westward, by the completion of E. H. Moore's Union Sugar No. 2 and Union Oil Company's LeRoy No. 2. This westward trend has been verified by the completion of several good wells in each of the three isolated areas west of the Beacon area. Whether the field will extend much farther westward is problematical, and will have to be ascertained by drilling. It is probable that edge-water conditions will also determine the western limit of the field.

PRODUCTION

At the present time[3] there are about 130 wells in the field that either are being produced or are ready to produce. The estimated potential production of these wells is 100,000 barrels, or more, per day. Potentials of individual wells vary from 25 to more than 5,000 barrels per day. It is estimated that a few wells have potentials as high as 6,000–10,000 barrels. Since the field was put on production in the middle of April, 1937, approximately 3,500,000 barrels of oil have been produced from the active wells. Daily production has ranged from 3,800 to more than 12,000 barrels. The curtailed production of the field is about 12,000 barrels per day.

The crude varies from approximately 12° to 17.5° gravity (A.P.I.), and averages 16.5°. It has an asphaltic base, contains about 4 per cent sulphur, and has about 20 per cent natural gasoline and distillate content. The oil is fairly clean, with less than 2 per cent cut, although in a few wells water has been found in considerably larger percentages. The gas-oil ratio in producing wells is low in comparison with those along the Santa Barbara Coast, and averages about 200 cubic feet of gas per barrel of oil.

STRATIGRAPHY

GENERAL STATEMENT

Since 1912, a total of about 190 oil wells, wildcats, and core holes have been drilled in the Santa Maria Valley. The stratigraphy pre-

[3] September 1, 1938.

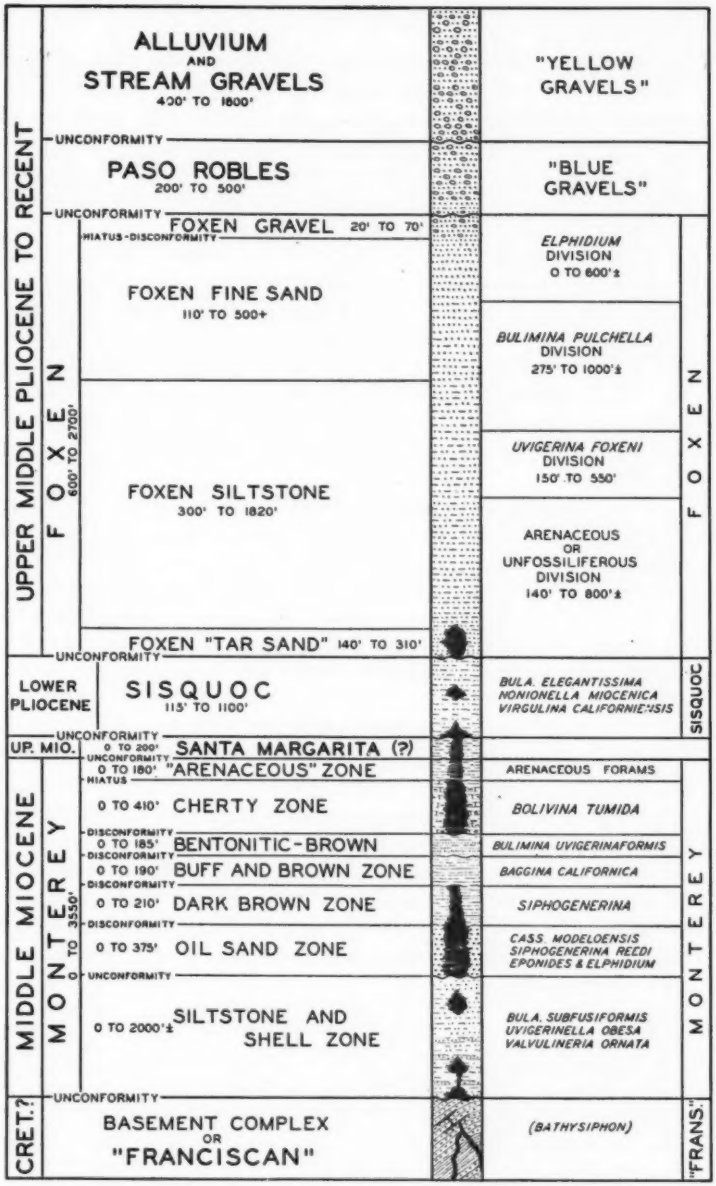

FIG. 3.—Standard stratigraphic section of Santa Maria Valley oil field.

sented here is based on a detailed study of core and ditch samples, logs and histories of the great majority of these wells. The writer was especially fortunate in having begun paleontological studies in the district prior to the discovery of the Santa Maria Valley field, and then being able to follow closely the development of the field to the present time. As a result it has been possible to work out in great detail the stratigraphy and micropaleontology of the area.

To date, there are seven lithologically and faunally distinct formations recognizable below the surface of the Santa Maria Valley. Two of these formations have not been published. One of these, the Recent (or Pleistocene ?) alluvium and stream gravels that cover the floor of the Santa Maria Valley to a depth up to 1,600 feet, might be called the "Santa Maria" formation,[4] although it has never been distinctly designated as such, by itself. The other formation not formally described is the Middle or Upper Pliocene Foxen, named by C. F. Tolman.[5]

The following stratigraphic nomenclature for the Santa Maria Valley oil field has been established, to a large extent, by the writer, and in various stages of perfection has been used successfully for more than four years. Aside from the broader formational terms, the nomenclature given here pertains exclusively to the Santa Maria district, and particularly to the Santa Maria Valley. The standard stratigraphic section is shown in Figure 3.

Geological Formations

The formations encountered in the Santa Maria Valley include: (1) Recent (or Pleistocene ?) alluvium and stream gravels, (2) Pleistocene or Pliocene Paso Robles formation, (3) Upper or Middle Pliocene Foxen formation, (4) Lower Pliocene Sisquoc formation, (5) Upper Miocene Santa Margarita(?) formation, (6) Middle Miocene Monterey formation, and (7) the so-called "Franciscan" basement rock of Cretaceous (?) age. It is possible that the Siltstone and Shell zone of the basal part of the Monterey, described later, should be considered as a separate formation.

[4] C. M. Carson, *Pan-Amer. Geol.*, Vol. 43 (1925), pp. 265–270.

[5] The Foxen formation was originally named by Professor C. F. Tolman of Stanford University at the January, 1926, meeting of the Cordilleran Section of the Geological Society of America. Unfortunately nothing was published by him concerning the formation and type locality. Unfortunate, also, is the fact that there is no Foxen in Foxen Canyon, the locality from which the name was derived. Nevertheless, the name Foxen has become firmly established among geologists and paleontologists working the Santa Maria area, and although the name does not adhere strictly to geologic principles, it seems imprudent to attempt to give a new name to the formation. Foxen is a good local name and will no doubt continue to be used for some time to come.

RECENT TO PLIOCENE

ALLUVIUM AND STREAM GRAVELS

The floor of the Santa Maria Valley has been filled to a depth varying from 50 to 1,600 feet with Recent (or Pleistocene ?) alluvium and stream gravels, the thickest part being in the central part of the valley. In the Santa Maria Valley oil field proper, the gravels vary from 400 to 1,600 feet in thickness. The formation consists of interbedded unconsolidated fine to coarse quartzitic sands and fine to bouldery gravels, the pebbles of the latter being composed of major amounts of quartzite and acidic and basic igneous rock, and minor amounts of Monterey shale and chert. The sands and gravels contain lenses and beds of yellowish brown clay, which impart their color to ditch cuttings when drilling through the formation. The section has been locally called the "Yellow gravels." In the lower part of the formation, generally in the central part of the valley, there are a few intercalated beds of light bluish gray and light greenish buff sand, gravel, and clay, which may be used locally for correlation purposes. In general, however, the first appearance of blue gravels and clays marks the top of the Paso Robles formation. No fossils have been found in the alluvium and stream gravels, and it is believed that the formation is all non-marine.

PASO ROBLES FORMATION

The name Paso Robles is applied to the series of blue gravels and clays immediately underlying the "Yellow gravels," because of the correspondence in position and lithology to similar beds named by H. W. Fairbanks[6] in the near-by San Luis area. The formation in the valley varies from 50 to 500 feet in thickness, and in the Santa Maria Valley oil field from 200 to 500 feet. The Paso Robles,[7] locally called the "Blue gravels," consists of interbedded unconsolidated fine to coarse sands and, rarely bouldery, rounded and angular gravels, which are composed of a large percentage of pebbles of Monterey shale and chert. Beds and lenses of light bluish gray clay are intercalated with the sands and gravels. A few fresh-water limestones are locally present in the lower part of the formation. The Paso Robles is apparently unfossiliferous, except for a few lenses of marine sands near the bottom which contain a sparsely distributed mega-fauna and rare foraminiferal assemblage. These fossil beds can be used locally for correlation purposes. Brackish-water gastropods and ostracods are also found in the local limy beds in the formation.

[6] *U. S. Geol. Survey Folio 101* (1904), pp. 4–5.

[7] Sometimes known as "Schumann formation" (an unnecessary name).

There is an unconformity of variable magnitude at the base of the Paso Robles in surface sections, but in well sections this unconformity does not seem to be recognizable by lithologic means. However, the unconformity can be determined by studying the faunal horizons that occur in the upper part of the Foxen.

FOXEN FORMATION

The top of the Foxen is marked in well sections at the first appearance of numerous and continuously occurring sea-shell fragments in ditch cuttings. It is also the top of continuous foraminiferal beds. The *continuous* part of the foregoing statements is stressed, because, as mentioned before, there are a few fossiliferous beds found in the marine fingers of the lower part of the Paso Robles. The Foxen section is slightly different in each of the several drilled areas in the Santa Maria Valley field, due to facies change in lithology and fauna. In general, there is considerable difference between the Foxen section in the field and that in the central part of the valley, in the vicinity of the small town of Betteravia. For this reason it seems best to treat the section at Betteravia separately. The general relationship of the various Foxen sections is shown in Figure 4.

Betteravia area.—The thickest and most complete section of the Foxen formation is that found in the central part of the Santa Maria Valley, in the vicinity of the small town of Betteravia. In this district the formation is approximately 3,620 feet thick. The Foxen in the most westerly extension of the field, although only 2,475–2,700 feet thick, has much the same general lithologic and foraminiferal divisions as those found in the Betteravia section, but this is the only section in the field that is similar to that in the central part of the valley. The formation in the Betteravia area can be divided into two more or less distinct members: (1) an upper sand unit called the fine sand member, which can be definitely correlated with the Foxen and "Yellow sand" ("Careaga formation"[8]) section exposed in the surface section at Schumann Cut, in the Casmalia Hills; and (2) a lower unit, the siltstone member, which is that part of the Foxen formation not generally present in surface sections, although a meager exposure does occur on the north side of Harris grade in the Purisima Hills.

Fine Sand member.—The Foxen fine sand member of the Betteravia section is approximately 625 feet thick. It is composed essentially of fossiliferous, slightly consolidated light bluish gray to light green-

[8] An unpublished name proposed by some field geologists for a mappable yellow sand unit which occurs in the Santa Maria district. The section is probably partly upper Foxen in age and can not be distinguished in most subsurface correlations.

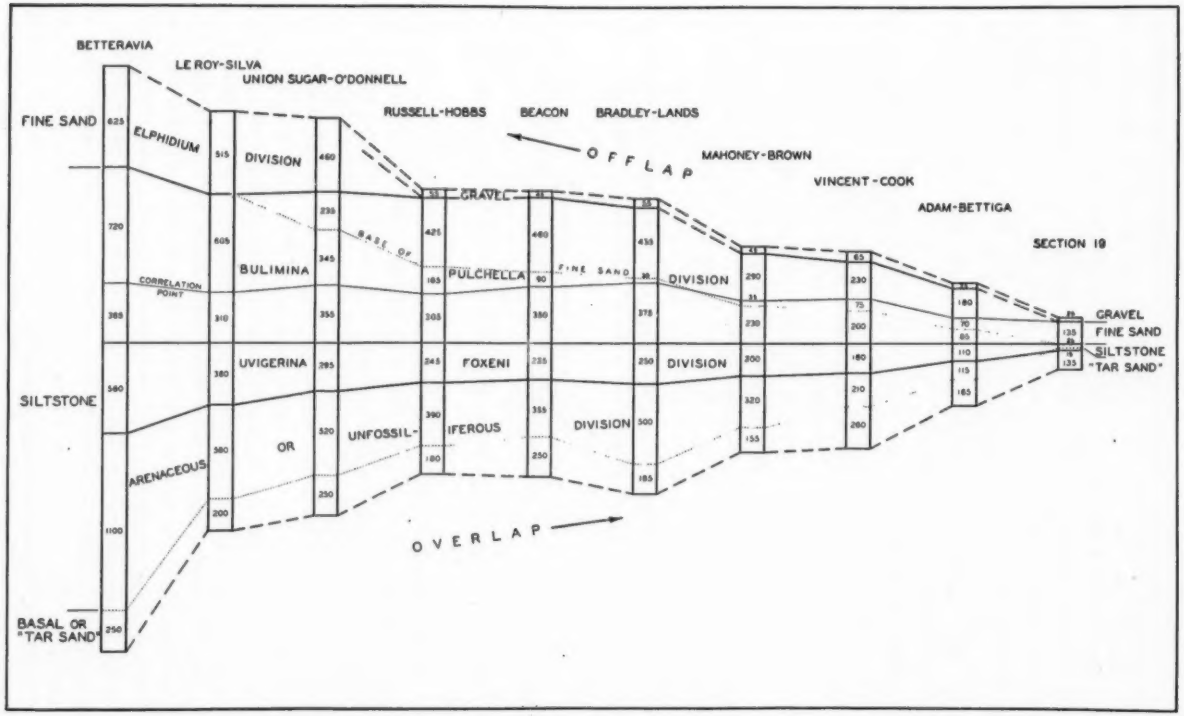

FIG. 4.—Generalized Foxen sections in Santa Maria Valley to illustrate overlap-offlap nature of formation.

ish gray fine to medium sand, together with a few beds and lenses of medium to fine gravels in the upper part, and streaks of silty clay in the lower part. A few beds of impure concretionary limestone are also found in the upper part of the member. The fine sand member in the Betteravia area includes only the *Elphidium* division of the Foxen formation, being characterized by *Elphidium hannai* Cushman and Grant and *Elphidium hughesi* Cushman and Grant. In other parts of the valley, the lithologically sandy phase of the Foxen extends farther down into the section (Fig. 4).

Siltstone member.—The lower 3,000 feet of the Foxen formation in the Betteravia area consists of fossiliferous slightly to fairly well consolidated light olive-gray to dark olive-brown siltstone, with about 250 feet, or more, of cross-bedded silty sand and sandy siltstone at the base. The member can be divided into three faunal units, or divisions: (1) an upper 1,085-foot *Bulimina pulchella* division, (2) a middle 560-foot *Uvigerina foxeni* Ms. (n. sp.) division, and (3) a lower 1,350-foot "Arenaceous" division, or division of arenaceous Foraminifera.

Altogether, nearly 100 usable foraminiferal zones, subzones, and horizons have been made in the combined section of Foxen fine sand and siltstone in the Betteravia area.

Santa Maria Valley oil field.—The Foxen formation in the Santa Maria Valley oil field proper varies from 600 to 2,700 feet in thickness. It can be divided into four lithologic units, or members: (1) a gravel member, (2) a fine sand member, (3) a siltstone member, and (4) a "tar sand" member.

Gravel member.—The Foxen gravel member in the Santa Maria Valley oil field varies from 20 to 70 feet in thickness. It is essentially a fossiliferous unconsolidated series of light bluish gray fine to coarse sands and gravels. In places, the top of the gravel member has a few thick beds of impure concretionary limestone. The pebbles of the gravels consist of Monterey chert, blue quartzite, acidic igneous rock, basic igneous rock, and minor amounts of impure limestone. Freshly cored sands of this member give off a strong odor of hydrogen sulphide. A few partings of carbonaceous material are found in the finer sand phases. In the central and eastern areas of the field, this member is non-foraminiferal, but it is probably partly the facies equivalent of the upper part of the *Bulimina pulchella* zone, and partly equivalent to the *Elphidium* zone. In the western and far western areas of the field, the Foxen gravel occurs above beds carrying species of *Elphidium*. Hence, the gravel member apparently represents the last shore-line deposits left by the retreating Foxen sea. It is therefore ap-

parent that the gravels in various parts of the field are not exact time equivalents. This is illustrated in Figure 4.

Fine sand member.—The Foxen fine sand member varies from 110 to 500 (or more) feet in thickness. In the eastern part of the field, the top is taken at the base of the last gravel bed in the Foxen gravel member. In the central western part of the field, there are two sand phases in the Foxen: an upper one carrying *Elphidium*, which is gradational into a lower one carrying *Bulimina*. In all parts of the field, the lower part of the fine sand is gradational into the underlying siltstone. The sand member is essentially a fossiliferous soft, more or less unconsolidated, massive to rarely bedded light bluish gray to light olive-gray fine silty sand, varying from fine sand to sandy siltstone. When fresh, cores from this member also give off a strong odor of hydrogen sulphide. Bedding can be noticed only where partings of carbonaceous material separate layers of sandy siltstone.

The contact between the fine sand member and the underlying siltstone member is gradational and variable, being higher stratigraphically in wells where the Foxen formation is thickest (Fig. 4). In the far western part of the field, as in the Betteravia section, the fine sand does not extend below the bottom of the *Elphidium* zone. Thus, like the Foxen gravel, the fine sand is not everywhere exactly equivalent in age. Excluding the *Elphidium* part of the section, the fine sand member, together with the upper 50 to 925 feet of the following siltstone, constitutes the *Bulimina pulchella* division of the Foxen, the total thickness of which varies from 275 to 1,000 feet.

Siltstone member.—The Foxen siltstone member varies from 300 to 1,820 feet in thickness. As mentioned before, the top is gradational with the overlying fine sand. The base is taken at the top of the underlying "tar sand." The member is essentially a partly fossiliferous, slightly consolidated, massive light olive-gray siltstone. There are also a few beds, or lenses, of fine silty sand in the upper part, and in several places throughout the section there are streaks of hard calcareous sands (or "shells"). Small to large rounded light greenish gray impure phosphatic concretions are also found in the siltstone section. In deeper parts of the Santa Maria Valley, the lower part of the Foxen often consists of sparsely fossiliferous hard chocolate-brown somewhat siliceous siltstone.

The middle 110–550 feet of the siltstone member constitutes the *Uvigerina foxeni* division. In most of the field proper, the lower 140 to 800 feet of the siltstone member is generally unfossiliferous (nonforaminiferal), whereas in the Betteravia section and far western part

of the field, the lower part of the siltstone contains arenaceous Foraminifera.

"Tar sand" member.[9]—The Foxen "tar sand" member, in reality a basal sandy siltstone, or silty sand, varies from about 140 to 310 feet in thickness. It does not seem to be everywhere present in the field, but when occurring in the lower part of the Foxen formation, the top is taken on the first appearance of tar. This is not an exact stratigraphic point, since the top of the tar, or sand, is not consistent with foraminiferal markers (Fig. 4). However, its position does not vary enough to be disregarded in general local correlations. Wherever observed in well sections, the Foxen rests by slight but distinct unconformity on top of the Sisquoc formation. There is commonly a one-foot fossiliferous oil-saturated Sisquoc-shale-pebble conglomerate at the base of the Foxen "tar sand." The "tar sand" is essentially an oil-saturated (tarry) light olive-gray (stained brown) massive fine silty sand and sandy siltstone. It is, in general, cross-bedded. A few calcareous sandstones (or "shells") occur in the member. Internal black phosphatic molds of pelecypods and gastropods are found at several places in the oily beds, and especially in the basal conglomerate. A few "sporbo," or black phosphatic pellets, may be found in the zone, but these are probably reworked "sporbo" from the Sisquoc. The "tar sand," with only a few exceptions, is non-foraminiferal. This thin section, together with the thicker lower part of the siltstone member constitutes the Unfossiliferous (or "Arenaceous") division of the Foxen. The Unfossiliferous division varies from 140 to 800 feet in thickness. This thickness is in contrast to the lower part of the Foxen in the Betteravia area, where the section varies from 1,020 to 1,375 feet.

Correlation of Foxen formation.—In a very broad and general way, the entire foraminiferal fauna of the Foxen formation may be considered as a facies fauna, peculiar only to the Santa Maria basin. It is distinctly a local fauna, and so far as the writer is aware, its counterpart has not been found outside of the Santa Maria district. Faunas bearing the closest resemblance to that of the Foxen formation are found in the Upper Pliocene sections of the Los Angeles and Ventura basins, but these are not exact duplicates. The Foxen fauna is distinctly younger than Lower Pliocene, as represented by the Repetto fauna of the Los Angeles basin and similar faunas of the Humboldt

[9] The term "tar sand" is used for brevity. The quotation marks are essential because the "tar sand" is not everywhere tarry, nor is it everywhere a sand. The section is just an oily shale in some places. However, the basal part of the formation in the field is commonly an oil-saturated, or tarry, very fine silty sand, and for this reason the interval has been referred to as the "tar sand."

region of northern California. It appears to be even younger than the Lower Pico fauna of the Los Angeles basin. The *Elphidium* fauna of the Betteravia part of the valley appears to have some resemblance to that of a part of the San Joaquin clays and Etchegoin of the San Joaquin Valley. The fauna bears a closer resemblance, however, to parts of the Pliocene San Diego and San Pedro formations of Southern California. The fauna most closely approximating that of the Foxen fine sand and siltstone of the field proper is the Upper Pico fauna of the Los Angeles basin, which is considered by most geologists to be Upper Pliocene in age. However, the Foxen fauna may be a facies fauna older than Upper Pliocene. *Pecten healeyi* Arnold, considered by most paleontologists to be of upper Middle or lower Upper Pliocene age, occurs at the very top of the Foxen section. For this reason, it would appear that the entire formation is mostly Middle Pliocene in age. From a strictly foraminiferal standpoint, the fauna of the Foxen appears to be Upper Pliocene in age, and that is the view favored by the writer.

Ecological significance of Foxen faunas.—Without exception, the foraminiferal faunas in well sections of the Foxen show a gradual change, from bottom to top, from deeper- to shallower-water conditions. In the thickest Foxen sections, where the foraminiferal sequence is complete, the change is very regular, and the depth variation is well illustrated by minute differences in fauna. Without attempting to go into detail, the gradation of Foxen faunas with depth, in the Santa Maria Valley, can be shown by an abundance chart of the division-marker species (Fig. 5). It therefore appears that the Foxen basin was merely a moderately deep trough which gradually filled to the top with sediments.

Another gradational feature of the Foxen has already been mentioned. It is the lithologic facies change that takes place both at the base and at the top of the formation. In Figure 4 it is readily apparent that the basal sand rises higher and higher in the section, from west to east. The top of the sand is 1,100 feet below the base of the *Uvigerina foxeni* division in the Betteravia section, whereas in Sec. 19, T. 10 N., R. 33 W., the top of the sand is 15 feet above the base of that division. The same overlap condition also prevails from south to north in the Santa Maria Valley. That this overlap seems to be one of deeper water and not shore-line conditions, is attested to by three facts: (1) the silty nature of the sand, without any appreciable basal conglomerate, (2) the total absence of shore-line shallow-water megafossils, and (3) the complete absence of shallow-water Foraminifera. Apparently the initial subsidence of the Foxen basin was very rapid,

or the basin was mostly under water at the beginning of sedimentation.

The gradational change at the top of the Foxen is even better shown by the sections in Figure 4 than the one at the base of the formation. From east to west, and also from north to south, in the Santa Maria Valley, the Foxen fine sand member rises higher and higher in the section. At the eastern end of the valley, the base of the fine sand lies directly on top of the *Uvigerina foxeni* division, whereas in the

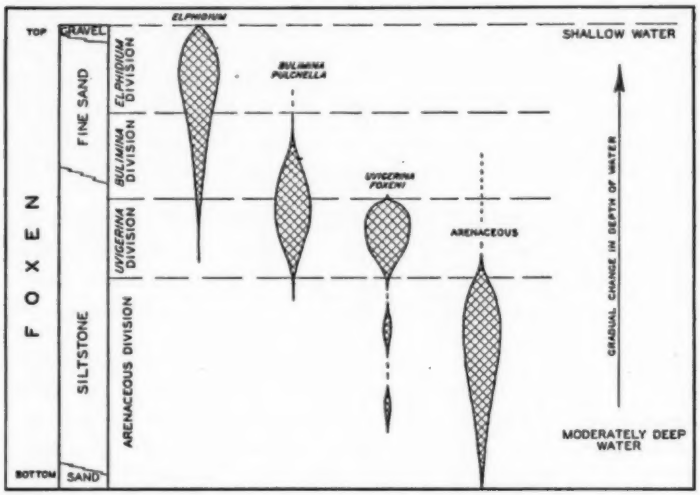

FIG. 5.—Relative abundance of Foxen division-marker species to show gradations from moderately deep to shallow-water conditions during Foxen time.

Betteravia section, the fine sand lies on top of the *Bulimina pulchella* division, 1,085 feet above the top of the *Uvigerina* section. This offlap condition is further substantiated by the Foxen gravel member which likewise rises progressively higher in the section toward the west and south. The gravel member is distinctly a shore-line sediment, and represents the last deposits laid down by the retreating Foxen sea. Whether the sandy phase of the *Elphidium* division ever existed in the extreme eastern part of the valley is problematical, but doubtful. It would appear that the sea retreated very rapidly from the eastern end of the valley, and that the gravel member varies in age from middle *Bulimina pulchella* time to late *Elphidium* time.

SISQUOC FORMATION

The Foxen-Sisquoc unconformity can rarely be detected in wells, except where the contact has been cored. However, it is readily apparent from detailed subsurface correlations. The Sisquoc formation rests on top of the Monterey and Santa Margarita(?) with sharp structural unconformity. The formation was named by William W. Porter, II[10] in 1932, from a locality in the lower Sisquoc Canyon, southeast of the Santa Maria Valley. The Sisquoc in the Santa Maria Valley varies from less than 50 to more than 2,300 feet in thickness. In the Santa Maria Valley oil field it varies from 115 to 1,100 feet. The formation consists of moderately indurated light greenish gray diatomaceous siltstone, in part fine sandy and fossiliferous, and in part oil-saturated. The formation is characterized by zones of siltstone containing small black phosphatic pellets, or "sporbo," and black phosphatic internal molds of pelecypods and gastropods. The Sisquoc carries a good foraminiferal fauna which seems to be the exact equivalent of that of the Reef Ridge shale of the San Joaquin Valley, which has sometimes been assigned to the lowermost Pliocene, and at other times to the uppermost Miocene. The writer favors a lowermost Pliocene age for the Sisquoc formation for the following reasons: (1) the unconformity between the Sisquoc and definite Miocene beds represents a very long period of time, distinctly a major time break; (2) the lithologic characters of the Sisquoc are totally different from those of the Santa Margarita(?)-Monterey; and (3) the foraminiferal fauna of the Sisquoc, through its counterpart, the Reef Ridge shale, is more closely related to that of the San Joaquin Valley upper Jacalitos-Etchegoin group, which is definitely Pliocene, than to Miocene faunas. This bears out the fossil findings of W. W. Porter, II,[11] in his work on the type Sisquoc. If the Sisquoc is of Lower Pliocene age, and the Foxen is Upper Pliocene, then the Middle Pliocene is absent from the Santa Maria district.

MIOCENE FORMATIONS

Since the oil production comes from the Miocene in the Santa Maria Valley oil field, the stratigraphy of that part of the section is the most important to study. From a stratigraphic standpoint, it is also the most difficult part of the section to work, and it has taken more than four years of study to present the column as it now stands. At present, only two Miocene formations are recognized in the area:

[10] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16 (1932), p. 139.

[11] *Ibid.*

the so-called Upper Miocene Santa Margarita(?) formation and the Middle Miocene Monterey formation.

SANTA MARGARITA(?) FORMATION[12]

In the southern part of the Santa Maria Valley oil field, and in general in the central part of the valley syncline, the Sisquoc is underlain by hard massive to well bedded semi-platy mouse-gray silty shale, siliceous in places, and in places interlaminated with gray silty sand. On the basis of relative position in the section, the silty shales have been tentatively assigned to the Santa Margarita(?). However, it may be determined later that the so-called Santa Margarita(?) is just a higher phase of the Monterey section. The thickness of the silty shales, where observed, varies from less than 10 to more than 200 feet. In the Betteravia area, where hard massive siliceous siltstones have been tentatively identified as Santa Margarita(?), the bottom of the formation has not been reached, but its maximum thickness must be at least 300 feet. No fossils, aside from a few indeterminable arenaceous Foraminifera, have been found in the formation. There is a distinct structural unconformity between the Santa Margarita(?) and the overlying Sisquoc. The break between the Santa Margarita(?) and the Monterey, however, is not so pronounced, but subsurface studies seem to indicate a small disconformity, or hiatus, between the two formations. It is indicated by the presence of a small slightly conglomeratic basal sand that has been found in a few wells in the lower part of the Santa Margarita(?). In certain wells the Santa Margarita(?) contains oil, and seems to be responsible for some production. However, no extensive selective tests have been made to determine just how much oil the formation is contributing.

MONTEREY FORMATION[13]

A rather sharp structural unconformity marks the top of the Monterey formation in the Santa Maria Valley, except where the so-called

[12] The term Santa Margarita(?) is used in this paper primarily to indicate a lithologic zone that can be distinguished in the Miocene section in subsurface correlations. The presence of true Santa Margarita rocks in the Santa Maria Valley can not be proved. However, the term has been used by various authors and geologists working in the area, and is therefore retained in this paper. If the rocks indicated as Santa Margarita(?) are really post-Monterey, the name Pismo might be more applicable, since it was used to designate such rocks in the San Luis area on the north. Many geologists and paleontologists use the term Santa Margarita to include all of the rocks in the section down to the *Baggina californica* zone. The writer does not favor such usage. The name Santa Margarita(?) probably should be dropped from the Miocene section in the Santa Maria Valley, and some appropriate zonal name, such as Unfossiliferous zone, substituted.

[13] The term Monterey is used in this paper to include all of the strata between the Santa Margarita(?) and the "Franciscan." To date, no earlier Tertiary rocks have been found in the Santa Maria Valley.

Santa Margarita(?) intervenes below the Sisquoc. The stratigraphic thickness of the Monterey, so far observed in the area, varies from a few feet to more than 5,000 feet, but in the field proper its maximum thickness seldom exceeds 1,200 feet. The Monterey pinches out to the north where a few holes drilled in the valley have found the Monterey completely missing from the section. Toward the south and east, the Monterey thickens fairly rapidly, increasing from only a few feet to more than 3,000 feet in a little less than two miles. In the central eastern part of the Santa Maria Valley the Monterey is probably 7,000 feet thick.

The Monterey in the Santa Maria Valley can be divided into seven distinct lithologic and faunal units, each separated by local (and in part, state-wide) disconformities. In a sense, the Monterey should be considered as a group composed of seven different stratigraphic units, or formations. In this paper the distinct parts of the Monterey are merely designated as zones, which from top to bottom include: (1) "Arenaceous" zone, (2) Cherty zone, (3) Bentonitic-Brown zone, (4) Buff and Brown zone, (5) Dark Brown zone, (6) Oil Sand zone, and (7) Siltstone and Shell zone. A chart contrasting the various sections of Monterey in the field is shown in Figure 7.

"Arenaceous" zone.—The highest definite Monterey beds encountered so far in the Santa Maria Valley oil field consist of 10 to 180 feet of fractured hard brown platy shale, rarely massive, siliceous, and silty. The shales are characterized by the presence of rare to abundant indeterminable arenaceous Foraminifera, from which the section takes its name. The top of the zone is thus located by the first appearance of continuously-occurring arenaceous Foraminifera in the Monterey section. In some parts of the zone, the bedding planes of the shale are coated by a thin veneer of drusy pyrite; in other parts, the shale contains medium-sized thinly flattened patches of buff phosphatic material. Most of the shales of this zone are stained with oil, which is especially pronounced along the bedding planes and fractures. When silty, the "Arenaceous" zone is, in many places, more or less saturated with oil, and yields some production.

Cherty zone.—Separated by a small hiatus from the "Arenaceous" zone, the next Monterey beds encountered in the field consist of 20 to 410 feet of fractured hard brown platy partly siliceous shale, containing many banded layers of dark brownish black and brownish gray chert. The cherty shales generally contain a rich foraminiferal fauna, characterized by *Bolivina tumida* Cushman and Kleinpell. This fauna is not always present at the top of the cherty section, so that the top of the zone is generally placed at the first appearance of black

or gray chert. A large part of the oil production of the field is obtained from this fractured cherty part of the Monterey. The zone may be divided into four distinct lithologic and foraminiferal subzones, characterized in order from top to bottom by *Bolivina tumida*, "granular" yellowish chert, *Nonionella-Virgulina*, and *Gümbelina-Valvulineria*.

Bentonitic-Brown zone.—Disconformably below the Cherty zone occurs 25 to 185 feet of section, consisting of moderately hard banded light and dark brown platy foraminiferal shale, having a large number of streaks and thin beds of yellowish, grayish, and greenish bentonite. Most of the upper one-third of the shale series is partly siliceous, in some places containing distinctly cherty beds. Where present, the lowest part of the zone contains small irregularly shaped nodules of phosphatic material. Besides the presence of bentonite in the section, the most characteristic feature of the zone is the interlaminated and interbanded occurrence of moderately hard dark brownish black fissile shale, either entirely unfossiliferous or containing numerous flattened arenaceous Foraminifera on the parting surfaces. The top of the zone is located at a faunal break, the second abundant occurrence of *Bolivina tumida* in the Monterey section, just above the first appearance of the fissile shale. In a general way, the top of the zone can be placed at the first appearance of bentonite below the main part of the chert. The section may be divided into four foraminiferal subzones, characterized in order from top to bottom by *Bolivina tumida* Cushman and Kleinpell, *Bulimina uvigerinaformis* Cushman and Kleinpell, a second *Bolivina tumida* Cushman and Kleinpell, and an unfossiliferous interval marked by crab remains and phosphatic nodules. The Bentonitic-Brown zone is ordinarily not stained, and nowhere saturated with oil. The section is relatively impervious, except where highly fractured.

Buff and Brown zone.—This section is composed of a series of moderately hard interbedded chocolate-brown semi-platy foraminiferal and buff-colored phosphatic shales. A few scattered streaks of yellowish green bentonite are present in the upper part of the zone. The zone varies from 30 to 190 feet in thickness. Lithologically, the top of the Buff and Brown zone is taken at the first appearance of the interbedded phosphatic layers in the Monterey below the fissile shales of the Bentonitic-Brown zone. Faunally, the top of the Buff and Brown zone is marked by the first appearance of *Baggina californica* Cushman in the section. The fauna of this interval is very plentiful, making it possible to establish eleven foraminiferal marker-horizons. The three main subdivisions of the zone are characterized in order from top to bottom by *Pulvinulinella gyroidinaformis* Kleinpell Ms.,

Pulvinulinella capitanensis Cushman and Kleinpell, and a normal *Baggina* fauna. From detailed studies and correlation with other sections, it has been found that the disconformity at the top of the Buff and Brown zone corresponds with a well recognized break that occurs between the cherts and *Baggina* zone all over the southwestern part of California. Parts of the *Baggina* zone higher than *Pulvinulinella gyroidinaformis* are not found in the Santa Maria district. The Buff and Brown zone, unless broken up by faulting, is apparently impervious and devoid of oil.

Dark Brown zone.—Disconformably below the Buff and Brown zone occurs a moderately hard series of fractured finely interbedded chocolate-brown and buff phosphatic semi-platy foraminiferal shale. The shales may be either darker or lighter in color than those in the *Baggina* zone, but since the zone is generally stained a dark color by oil saturation the interval has been called the Dark Brown zone. The interlaminated beds of buff phosphatic shale are, as a rule, thinner and less interrupted than those in the Buff and Brown zone. Bentonite is apparently not present in this interval. The zone varies from 10 to 210 feet in thickness. The top of the section can not always be located accurately by lithology, but is marked faunally by the first appearance of species of *Siphogenerina* in the Monterey formation. Like the preceding zone, the Dark Brown zone contains a very rich foraminiferal fauna, making it possible to establish sixteen foraminiferal marker horizons. The five main divisions of the zone are characterized in order from top to bottom by *Siphogenerina bettigensis* Ms. (n. sp.), *Siphogenerina collomi* Cushman and *Siphogenerina nuciformis* Kleinpell Ms., *Siphogenerina reedi* Cushman, *Cancris baggi* Cushman and Kleinpell, and a second *Siphogenerina reedi* Cushman. The lower two-thirds of the section contains numerous *Siphogenerina branneri* (Bagg). *Anomalina salinasensis* Kleinpell Ms. can be used as a marker for the Dark Brown zone as well as species of *Siphogenerina*. From detailed studies, it has been found that the disconformity at the top of this zone compares with a similar break found in sections elsewhere in California. The Dark Brown zone corresponds to the lower four-fifths of the *Valvulineria californica* zone of the Monterey of the San Joaquin Valley. The Dark Brown zone is usually more or less saturated with oil especially in the lower part where a large abundance of phosphatized Foraminifera gives the rock a texture comparable to a fine sand.

Oil Sand zone.[14]—In some parts of the field, immediately underlying the Dark Brown zone, occurs the Oil Sand zone, which varies

[14] The term Oil Sand zone is used primarily to designate a distinct lithologic and faunal zone in the section. Other oil sands occur in the Siltstone and Shell zone.

from a few feet to 375 feet in thickness. Recent studies indicate that the Oil Sand member in the Santa Maria Valley field is a shore-line sand, occurring only along the northern border of the local Monterey basin where the formation overlaps against the "Franciscan." The sand is distinctly a basal member of the shale part of the Monterey section, since it carries, in many places, the same general fauna as the shale interval, and is separated from the Siltstone and Shell zone by an unconformity. The sands in the Western Extension part of the field are relatively uniform in character, consisting for the most part of partly oil-saturated, in places fossiliferous, soft to hard medium-grained pyritiferous arkosic sand, containing many grains and fragments of serpentinous material. The member in this area is distinctly a basal sand, and rests as a relatively thin veneer directly on the "Franciscan."

The Oil Sand section is best developed in the original field area (Fig. 2). In this part of the field, the member is, as a rule, very silty at the top and contains a very good foraminiferal fauna, characterized by *Siphogenerina reedi* Cushman and *Cassidulina modeloensis* Cushman and Kleinpell (Rankin Ms.). Subsurface studies indicate that these silty sands grade laterally into the lower shales of the Dark Brown zone. Below the silty part of the Oil Sand zone the sands become somewhat coarse and calcareous. They contain a fairly rich macro- and micro-fauna, characterized by a small variety of *Pecten andersoni* Arnold, species of Bryozoa, echinoid spines, minute cup corals, *Elphidium crispus* (Linné), *Cassidulina modeloensis* Cushman and Kleinpell (Rankin Ms.), and a small species of *Cibicides* (similar to *Cibicides conoideus* Galloway and Wissler). For the most part, the sands in the eastern portion of the field are all oil-saturated. However, they are relatively unconsolidated and cause considerable trouble in pumping wells. A few calcareous sandstones (or "shells") are found in the section, but these are relatively rare in comparison with those found in the Siltstone and Shell zone. Because of the good foraminiferal fauna found in the Oil Sand zone, local correlations are possible from well to well, but some care must be used in attempting any long-range correlations, since fine sands grade to medium, coarse sands grade to fine, and faunas change facies very rapidly.

Siltstone and Shell zone.—Recent drilling in the southeastern part of the Santa Maria Valley field has uncovered a new fossiliferous and lithologic zone, separated from the rest of the overlying Monterey by distinct unconformity. The zone is probably deserving of a separate formational name,[15] since it does not resemble any of the overlying

[15] The name Point Sal formation will be proposed for the Siltstone and Shell zone

Monterey, and is not of Temblor age. The zone varies in thickness; its maximum is 2,000 feet. It is composed of soft to hard, massive to well bedded pyritiferous steel-gray siltstone and silty shale, containing thick beds of cavernous gray fine to coarse calcareous sandstone, or "shells." Some parts of the section consist of well bedded interlaminated gray-brown silty shale and light gray silty sand. The siltstones and "shells" are interrupted at intervals by lenticular streaks and beds of partly to wholly oil-saturated fine to medium sand.

The Siltstone and Shell zone carries a very good, though nowhere abundant, local silty facies foraminiferal fauna, which is characterized by *Buliminella subfusiformis* Cushman, *Valvulineria ornata* Cushman and *Uvigerinella obesa* Cushman. The fauna of this section has not been completely studied, but, from present indications, seems to be related to the Gould shale fauna of the San Joaquin Valley. It appears to be related to the Santa Barbara Coast section below the *Valvulineria californica* zone and above the *Haplophragmoides* (brown clay shale) zone of the Rincon formation. For the purposes of this paper, the zone is placed as basal Monterey.

"FRANCISCAN"[16]

Underlying the Monterey, and separated from it by sharp unconformity, occurs the so-called "Franciscan" formation, a moderately folded, faulted, and somewhat altered basement rock. So far, no other formation has been found between the Monterey and the "Franciscan" in the Santa Maria Valley. No definite Temblor is present in the district. In the part of the valley adjacent to the Casmalia Hills, however, there may be some "Red Beds" (of Miocene age?) occurring below the Monterey. The occurrence of such rocks has not been recorded in any well to date, but they are known to exist in surface outcrop in the Casmalia Hills. The "Franciscan" has been penetrated by the great majority of wells drilled in the Santa Maria Valley field, but nowhere to any appreciable depth. The rocks encountered vary somewhat in lithologic character. So far as observed, the main basement rock is a fractured and calcite-veined hard green-

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in the near future, from the type locality of the zone on the Point Sal grade, approximately one-half mile east of the old Point Sal Landing (Guadalupe Quadrangle). The type locality has not been completely studied, so that a complete description of the formation can not be given at this time.

[16] Recent studies in the Santa Maria Valley indicate that the rocks referred to as "Franciscan" are probably of Panoche-Cretaceous age, and that there are no true Jurassic Franciscan rocks in the local area. In the old unrestricted usage of the term Franciscan to include rocks of both Cretaceous and Jurassic age, the name "Franciscan" can be used to designate the basement rocks. It has been used as such in this paper.

ish gray pyritiferous calcareous medium-grained sandstone, of different character from the "shells" in the lowest Monterey zone, and distinctly different from true Franciscan rocks found in the mountains to the north. In disturbed areas with local basic intrusions, two other types of rock are found: (1) a highly faulted, fractured, and slickensided gouge-like gray pyritiferous clay-shale, and (2) a highly slickensided gouge-like impure serpentine. A few Foraminifera have been found in the so-called "Franciscan," which suggest a Cretaceous age for the formation. Hence, the rock is probably not true Franciscan in the restricted sense, implying Jurassic age. The "Franciscan" contains no oil other than that which has migrated into the formation from the Monterey.

Oil Zones

There are four distinct oil horizons present in the Santa Maria Valley oil field, of which only the two in the Miocene are productive under present methods of operation. The first oil horizon is the "tar sand" at the base of the Foxen formation. Much of this sandy siltstone (or silty sand) is completely saturated with a very heavy tar-like oil, from which practically all volatile constituents have disappeared, leaving only an asphaltic residuum. If accessible, the "tar sand" would make a very good road material, but it is buried under 1,500 to 3,000 feet of gravels, sands, and siltstones. The "tar sand" averages about 150 feet in thickness, and is known to cover a subsurface area of more than 20 square miles.

Several fairly good oil showings are found in the Sisquoc formation, particularly in the basal part of the section. These oil showings constitute the so-called second oil horizon. The oil is very heavy and tar-like, but some gas appears in the ditch when drilling through the formation. Various parts of the Sisquoc have been cored in several wells drilled in the valley, but on account of low porosity, incomplete saturation, small gas showings, and tar-like nature of the oil, the formation has not been thoroughly tested. Aside from the basal sand, the Sisquoc in the Santa Maria Valley field, so far as observed, will probably not produce any oil under present methods of production.

The Miocene is the oil-producing section of the Santa Maria Valley field. It is usually completely penetrated and left open in producing wells. The oil, however, comes principally from two separate horizons: (1) an upper zone comprising the Santa Margarita(?), "Arenaceous," and Cherty units, and (2) a lower zone comprising the Dark Brown, Oil Sand, and Siltstone and Shell units. The upper oil zone has a fairly high porosity, or permeability, due to the fractured character

of the brittle cherty shales. Wells having this zone in their section are, as a rule, among the best producers in the field, especially if in the proximity of a fault zone. The larger part of the gas in the field probably comes from the upper oil zone. Although no extensive selective tests have been made, it appears that the lower oil zone is less productive than the upper zone and contains oil of a different gravity. The oil seems slightly more tarry and heavier, and the gas content appears to be lower. Also, the loose character of the sand causes more production troubles than that encountered in the higher zone.

All of the oil occurring in the Foxen and Sisquoc formations certainly appears to have been derived from the underlying Monterey. It has followed faults and fractures through the Monterey shales and permeated the more porous parts of the overlying sediments. However, neither the Sisquoc nor the Foxen contains suitable impervious beds sufficient to trap the more volatile constituents of the oil. The Foxen "tar sand," especially, may be considered as a vast underground oil seep. For these reasons it is believed that only low-gravity oil can be expected in the Santa Maria Valley area.

In general, the amount of production of oil in the Santa Maria Valley oil field seems to bear a direct relationship to the thickness and lithologic character of the Monterey formation, as follows.

1. Wells with the thickest Monterey sections are generally the best producers.

2. Wells with only the "Arenaceous" and Cherty sections are generally better producers than those with only the Dark Brown and Oil Sand zones.

3. With exceptions, the wells with thin shale sections and thick sand sections, especially the Siltstone and Shell zone, are poorer producers than wells with thick shale sections and thin sand sections.

4. With exceptions, wells whose sections are affected by major faults are generally better producers than any others.

Structure

The Santa Maria Valley oil field is located on the north limb of the Santa Maria Valley syncline. It may also be said to lie on the south limb of the broad anticline which occurs in the Nipomo Mesa area on the north. The producing Miocene sands and shales overlap northward over the "Franciscan" and buttress against the overlying Sisquoc (section *DD* in Fig. 8). The field is distinctly one of the overlap type of trap. It is unique in two respects: first, that production is derived from both shales and sands; and second, that the top of the producing section, in a sense a single reservoir, varies in excess of

3,000 feet in subsea elevation in the different wells. This sand-and-shale-producing overlap type of trap, with more than 3,000 feet of closure on top of the Miocene, distinguishes the field from any other in California. The fact that wells will flow at a 5,000-barrel rate with a gas-oil ratio of only 200:1 is also a noteworthy feature of the field.

The structure of the Santa Maria Valley oil field is by no means simple when compared with the typical anticlinal structures of California. Even though it is essentially a northward overlap of Miocene shales and sands over an old "Franciscan" basement, the folded, faulted, and eroded nature of the Miocene, together with local disconformities, makes nearly every well drilled in the field a semi-wildcat in regard to production. Almost any part of the Miocene, or none of it, can be expected below the gently dipping Foxen and Sisquoc formations. The structure of the Miocene below the Sisquoc is in some places rather complex. The "irregular" surface of the underlying "Franciscan" also makes it somewhat difficult to predict whether any basal sand can be expected in a new well. In general, the "Franciscan" "highs" are devoid of sand, whereas the "Franciscan" "lows" generally contain sand. Also, the presence of faults, both pre-Sisquoc and post-Sisquoc, makes prediction of Miocene thicknesses hazardous. Two generalized cross sections showing the structure of the Santa Maria Valley field are shown in Figure 6.

"FRANCISCAN"

The structure of the "Franciscan" is not well understood, as few wells have penetrated any thickness of basement rock. It is known, however, that the so-called "Franciscan" is not very highly metamorphosed, since the rocks cored still retain their sandstone and shale characters. Likewise, the "Franciscan" does not seem to be very much folded, except in local areas which have minor intrusions of serpentinized basic igneous rock. Nevertheless, some large orogenic movement must have taken place at the close of the "Franciscan," since it was upraised out of the sea and suffered considerable erosion, remaining a positive area from the end of the Cretaceous(?) to beginning Monterey time. The erosion that took place during that long period of time reduced the surface of the "Franciscan" to a gently rolling plain. The present "Franciscan" surface dips southwestward at approximately 15°–22°.

MIOCENE

The Santa Margarita(?)-Monterey group which overlaps the "Franciscan" presents varied minor local structures, not to mention

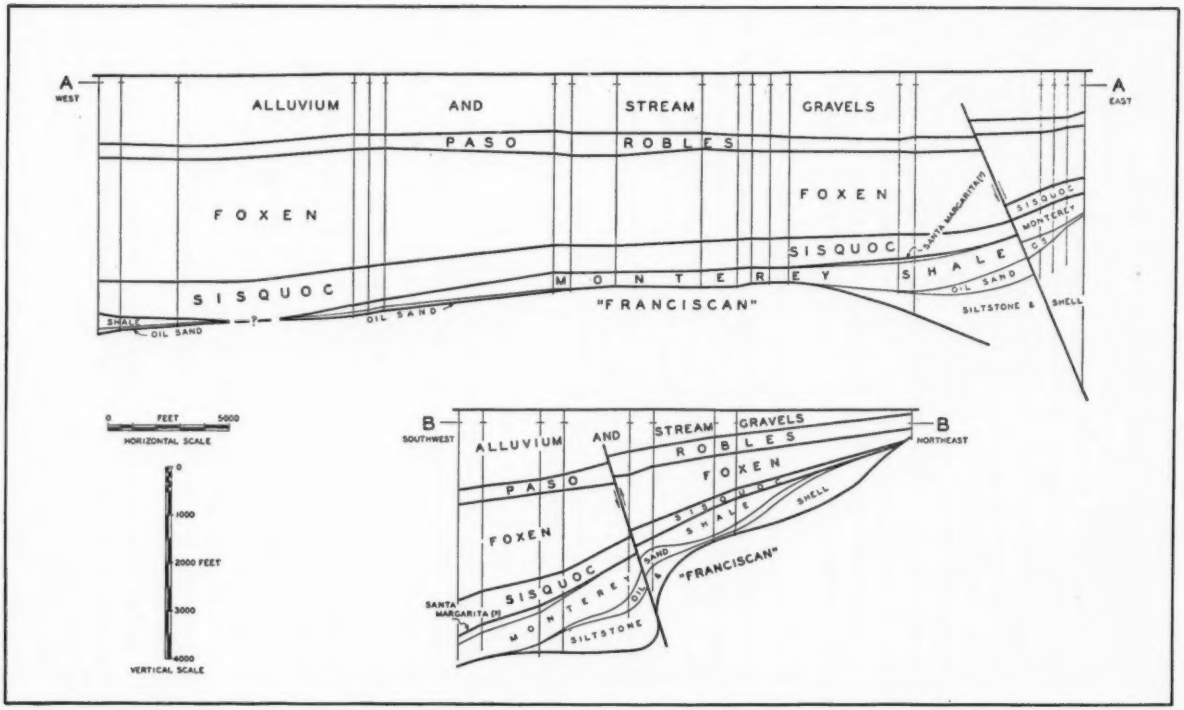

FIG. 6.—Generalized sections *AA* and *BB* across the Santa Maria Valley oil field.

the several disconformities within the group. Local pre-Sisquoc faults and contorted folds, especially minor crinkling of incompetent beds, are too numerous to show on any small-scale section. Most of the fracturing of the Cherty zone was caused by these local movements. The local disconformities and minor structural features, together with post-Sisquoc faulting, probably account for the "spotty" oil production in some parts of the field. The top of the Miocene has suffered considerable erosion, which beveled the various zones so that they now buttress against the overlying Sisquoc. This erosive action at the close of the Miocene must have been prolonged and vigorous, since the present Miocene surface is almost a plane (Fig. 2). The present eroded surface of the Miocene dips southwestward at approximately 13°.

The most important structural features of the Miocene are the local disconformities that occur in the section. The magnitude of these disconformities, together with the main unconformities at the top and bottom of the Miocene, directly controls the thickness of the section, which in turn has a direct bearing on the production of oil. The general nature of these stratigraphic breaks has been determined for various parts of the field (Fig. 7). A brief resumé of the variations in the Miocene sections of the different parts of the field is given in the following paragraphs.

WESTERN EXTENSION

On the whole, the Western extension (Fig. 2) has the thinnest section of Miocene found in the field. It is characterized by the total absence of the Santa Margarita(?) formation and the Siltstone and Shell zone of the Monterey. It is also marked by relatively thin sections of all other Monterey zones. It is further distinguished by a relatively thin consistent veneer of oil sand, resting on top of the "Franciscan." In general, potentials in wells of the Western extension are the smallest in the field, ranging from 50 to 1,075 barrels per day. The structure of the area is relatively simple. The Miocene dips gently southward, gradually thickening in that direction. The top is beveled and overlain by the Sisquoc, which overlaps onto the "Franciscan" on the north.

LeRoy-Silva area.—In the extreme western part of the Western extension of the field, the Miocene is consistently thinner than any found in the valley, varying only from 150 to 400 feet in thickness. This variable thickness depends upon the part of the Miocene in which the wells start. So far, in the area, only two wells possess any cherty section, and of that zone only the lower part (subzone 4) is

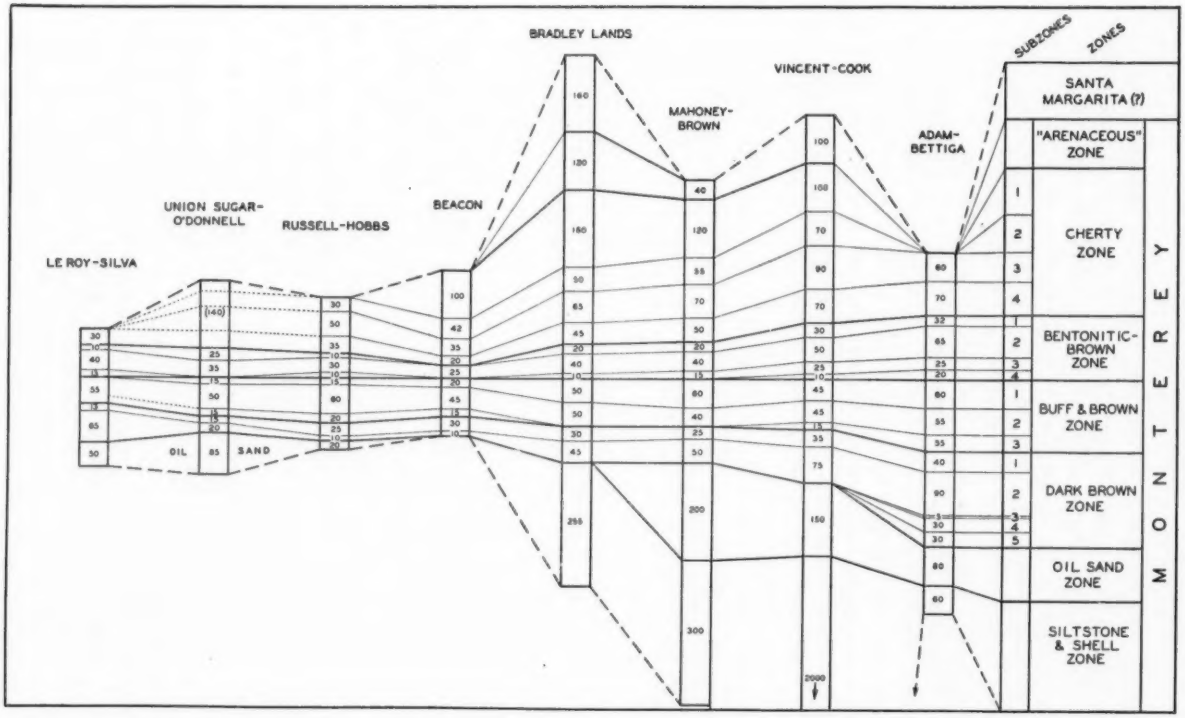

FIG. 7.—Generalized Miocene sections in Santa Maria Valley oil field to illustrate variable thicknesses and disconformities.

present. The other wells in the area begin in the Bentonitic-Brown or Buff and Brown zone. Where the Bentonitic-Brown zone is present, the basal part (subzone 4) is absent, and all of the other subzones are moderately thin. The Buff and Brown zone is about as thin in the LeRoy-Silva area as in any other part of the field. Only the lower two-thirds of the zone is present, the upper part having been eroded. The Dark Brown zone is above average in thickness, but even so, is represented merely by the upper two out of five possible subzones. The Oil Sand zone averages only about 50 feet in thickness, but in one well is almost 100 feet thick. As may be expected, the individual potential production of wells from the thin section of Miocene in the LeRoy-Silva area is small, and with just one exception does not exceed 275 barrels per day. So far, the LeRoy-Silva area is the poorest producing part of the field.

Union Sugar-O'Donnell area.—In the central part of the Western extension of the field, the Miocene varies in thickness from less than 200 feet on the north to slightly more than 500 feet on the south. The section is relatively thicker than that in the LeRoy-Silva area. The unconformity at the top of the Miocene cuts out the "Arenaceous" and Cherty zones on the north, but farther south these zones begin to appear and both are finally represented by complete sections. However, the two zones are much thinner than in the eastern part of the field. The disconformity between the Cherty and Bentonitic-Brown zones is not pronounced, since the lower and upper subzones, respectively, of the two zones are both partly present. The top of the Buff and Brown zone, however, is distinctly eroded and overlapped. Most of the upper subzone of the Buff and Brown zone has been worn away, and the two lower subzones of the Bentonitic-Brown zone are not represented. The Dark Brown zone is very thin in the Union Sugar-O'Donnell area, averaging only about 35 feet in thickness. Only thin parts of two subzones of the main zone are present. The Oil Sand zone varies from 50 to more than 100 feet in the various wells. Potentials of wells in the area are not very large, ranging from only 95 to about 700 barrels per day.

Russell-Hobbs area.—At the eastern end of the Western extension, in the Russell-Hobbs area, the Miocene section varies from 140 to 465 feet in thickness. At the southern end of the present development, the youngest Miocene present is the "Arenaceous" zone. The Cherty zone is well represented by all four subzones. To the north the Sisquoc lies on progressively lower Miocene until in the northernmost producing well it rests directly on the Buff and Brown zone. The disconformities between the various zones in the Monterey are readily

apparent from detailed subsurface investigation. The breaks between the Bentonitic-Brown, Buff and Brown, and Dark Brown zones are the most outstanding. The lower subzone of the Bentonitic-Brown zone and most of the upper subzone of the Buff and Brown zone are generally missing from the section. The Dark Brown zone is represented only by thin parts of the upper two subzones. In only a few places is the Oil Sand zone more than 20 feet thick in the Russell-Hobbs area, and in many places it is absent. Potentials in wells vary from 100 to 1,075 barrels per day.

BEACON AREA

The Miocene section in the Beacon area is moderately thin, varying from about 300 feet on the north to about 500 feet on the south. It is characterized by well-developed "Arenaceous" and Cherty zones, and the entire absence of Oil Sand zone. As a group, the Bentonitic-Brown, Buff and Brown, and Dark Brown zones are thinner in the Beacon area than in any other part of the field. Section *DD* in Figure 8 gives a good picture of the structural conditions existing in this area. The disconformities between zones are easily distinguishable. In the eastern part of the Beacon area the lower subzone of the Cherty zone is missing, indicating a local overlap. Subzones 1, 3, and 4 of the Bentonitic-Brown zone are nearly always missing, making the zone thinner than that found anywhere else in the field. All three subzones of the Buff and Brown zone are generally present, but the top and bottom subzones are nowhere complete. Only thin parts of the upper two subzones of the Dark Brown zone occur in the section. Potentials in wells in the Beacon area vary from 200 to as much as 4,000 barrels per day.

ORIGINAL FIELD

The eastern half of the Santa Maria Valley field, or that part called the Original field, is characterized by the thickest and best developed Miocene sections, which vary from 250 to 3,000 feet in thickness. The Santa Margarita(?), where present, and all of the zones in the Monterey are thicker and more completely developed in this area than elsewhere in the field. The area is particularly marked by thick sections of Oil Sand zone and Siltstone and Shell zone. Section *CC* in Figure 8 and section *BB* in Figure 6 show very clearly the structure of the Original field area. The overlap of the Miocene over the "Franciscan," and the buttressing of the beds against the Sisquoc are well illustrated by these sections. A thrust fault of about 200 feet displacement trends northwest-southeast through the middle of the district

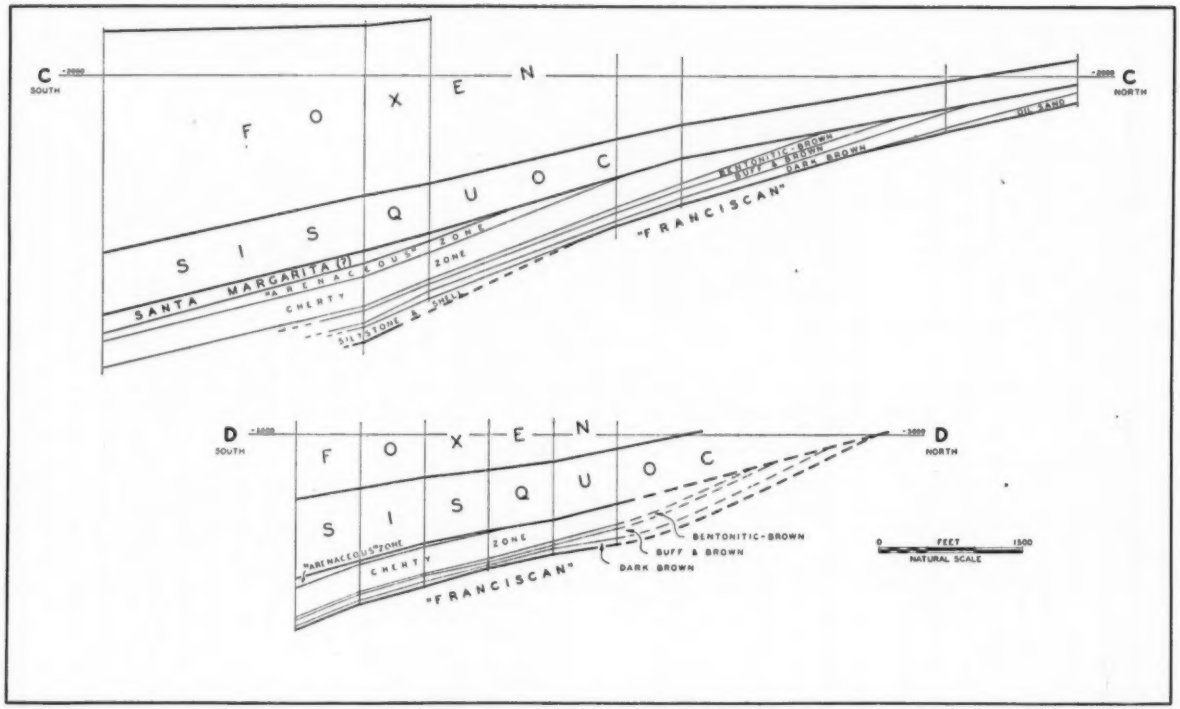

FIG. 8.—Generalized sections *CC* and *DD* to illustrate overlap and buttressing of Miocene.

(Fig. 2 and Fig. 6). This is the only major post-Sisquoc fault in the field. Wells located adjacent to the fault are the best producers in the field. Potentials of wells in the Original field area vary from 25 to more than 5,000 barrels per day. A few wells adjacent to the thrust fault can probably produce more than 8,000 barrels per day.

Bradley Lands area.—In the Bradley Lands area, the Miocene section varies from about 800 to 1,400 feet in thickness. The only Santa Margarita(?) so far found in the field occurs in this district. In one well a small sand carrying a few small pebbles of serpentine has been found at the base of the Santa Margarita(?). This suggests an unconformity between the two Miocene formations. The "Arenaceous" and Cherty zones are as well developed in the Bradley Lands area as anywhere else in the field. Disconformities between the different zones in the Monterey are shown by both erosion and overlap. The contact between the "Arenaceous" zone and the Cherty zone seems to be merely a small hiatus. The break between the Cherty and Bentonitic-Brown zones, however, in some places shows a slight erosion interval, the subzone at the top of the Bentonitic-Brown zone having been worn away before the Cherty zone was laid down. The Bentonitic-Brown zone overlaps the Buff and Brown zone, so that subzones 3 and 4 of the Bentonitic-Brown zone generally are missing. The lower subzone of the Buff and Brown zone is almost everywhere missing from the section, showing overlap on top of the Dark Brown zone. Only small parts of the upper two subzones of the Dark Brown zone have been found in the Bradley Lands area. The Oil Sand zone is practically absent, but a thick layer of the Siltstone and Shell zone has been found, in some places, reaching a maximum thickness of 440 feet. Potentials in wells of this area vary from 400 to 2,500 barrels per day.

Mahoney-Brown area.—The Mahoney-Brown area is characterized by an average development of all Miocene zones, with the exception of the Santa Margarita(?), which is absent. The particularly noticeable gaps in the section are found in the Bentonitic-Brown, Buff and Brown, and Dark Brown zones. Subzone 4 of the Bentonitic-Brown is missing from the section in most places. Subzone 3 of the Buff and Brown zone is likewise generally absent. The Dark Brown zone is represented only by the upper two subzones. Each of these omissions indicates local overlap conditions. The thickest section of the Oil Sand zone in the field occurs in the eastern part of the Mahoney-Brown area. The zone varies from less than 200 to more than 350 feet in thickness. The bottom of the Siltstone and Shell zone has not been reached in all wells in the area, but appears to be fairly thick,

varying from 200 to more than 450 feet. Potentials of certain wells in this area are the largest of any in the whole Santa Maria Valley field. Wells in the western part of the area produce only from 25 to 500 barrels per day, but those in the eastern part, along the thrust fault, make from 2,000 to more than 5,000 barrels per day. Two or three of these wells probably could produce as much as 8,000 to 10,000 barrels per day.

Vincent-Cook area.—The Vincent-Cook area is characterized by well developed Monterey zones. All subdivisions of the various zones are represented, with the exception of the Dark Brown zone, which has only the upper two subzones present. It was in this area that the true relationship between the Oil Sand zone and the Siltstone and Shell zone was first understood. It was found that a disconformity existed between the two zones, with a definite difference in dip of beds above and below the break. The Siltstone and Shell zone has a stratigraphic thickness of about 2,000 feet in the Vincent-Cook area.

The thrust fault which extends across the Original field apparently divides into two, or perhaps three, smaller thrusts in the Vincent-Cook area. These smaller faults form two or three small blocks, or wedges, which occupy an intermediate position, in general, with respect to the elevation of the two large blocks on either side of the main thrust. The district may be the focal point of an overturned fold which has yielded to a splintering action of the thrust movement. The idea of an overturned fold seems warranted because of the extremely steep dips encountered in the Monterey in wells of the Vincent-Cook area. On account of the faulted condition, potential production of wells in the area is "spotty" in nature—1,000-barrel wells offsetting 100-barrel wells. Individual potentials vary from 10 to more than 3,000 barrels per day.

Adam-Bettiga area.—From a stratigraphic standpoint, a better place to start than the Adam-Bettiga area, in discovering the Santa Maria Valley field, could not have been selected. It is the only place in the field where foraminiferal faunas were well enough developed to work out complete zonal variations, so that minor subzones and horizons could be established. Although the Santa Margarita(?), the "Arenaceous" zone, and most of the Cherty zone are missing from the section, all the other zones of the Monterey are better developed here than anywhere else in the field. Hence, the middle Monterey sections (e.g., Bentonitic-Brown, Buff and Brown, and Dark Brown zones) in the Adam-Bettiga area serve as a standard for the whole field. Potentials of wells in this area vary from 25 to 3,000 barrels per day.

PLIOCENE TO RECENT

The four formations, Sisquoc, Foxen, Paso Robles, and alluvium and stream gravels, which overlie the Miocene, are only gently tilted to conform with the broad synclinal structure of the valley. The formations are separated by unconformities, and each overlaps toward the north. Each formation was worn down almost to a peneplain before the succeeding one was laid down. Post-Sisquoc disturbances caused only broad folding and occasional faulting. Only one post-Sisquoc fault of any major consequence, in the Original field area, has been found so far in the Santa Maria Valley field. This fault, which probably resulted from renewed movement along an old Miocene structure line, is a high-angle thrust from the northeast. It is no doubt largely responsible for greater porosity and permeability in the Mahoney-Brown area, giving rise to the largest wells in the field. Minor post-Sisquoc faulting has affected two other areas in the field: the Russell-Hobbs and LeRoy-Silva areas in the Western extension. These disturbances, however, appear to be only local.

GEOLOGIC HISTORY

The geologic history of the Santa Maria Valley is relatively simple in its broader aspects. Only when an attempt is made to explain the disconformities in the Miocene section does the history of the region become involved. The succession of events is briefly told as follows.

After uplift of the "Franciscan," followed by a long period of erosion, lasting from late Cretaceous(?) to Middle Miocene time, the local Monterey seas came in from the south and finally covered the whole Santa Maria Valley area. The Siltstone and Shell zone was deposited under relatively shallow-water conditions in the southeastern part of the district. After a small uplift and erosion interval, the Monterey seas, depositing shale, overlapped northward over the old "irregular" surface of the "Franciscan," leaving a shore-line sand along the northern part of the area. Over this were deposited successively younger Monterey beds, which were locally elevated, eroded, and submerged from time to time to give the present disconformities and overlaps between the various zones. Monterey sedimentation culminated in the deposition of the "Arenaceous" zone. After the Monterey was gently elevated, slightly eroded, and locally submerged, the restricted Santa Margarita(?) formation was laid down in the central part of the valley.

At the close of the Miocene, the Santa Maria region was subjected to strong diastrophic forces which formed broad geanticlines and geo-

synclines in the area. At this time numerous local small folds, contortions, and faults were also developed and definite structural lines were established, which all later movements seem to have followed. The orogenic activity either completely raised the Miocene out of the sea, or else made the water shallow enough to allow marine peneplanation to take place. At any rate, before the Sisquoc was laid down, the surface of the Miocene was eroded to almost a perfect peneplain. In the northern part of the area, the Monterey was entirely stripped away, again exposing the "Franciscan."

Beginning in very early Pliocene time, the area was gently depressed and the Sisquoc formation was deposited. This formation, like the Monterey, overlapped northward, completely covered the Monterey, and encroached over the newly exposed "Franciscan." The break between the Sisquoc and the Foxen, while probably representing a long interval of Middle Pliocene time, does not suggest that any strong diastrophic action followed the deposition of the Sisquoc. Post-Sisquoc and pre-Foxen faulting has not been proved in the Santa Maria Valley, although renewed movement along Miocene fault lines may have occurred. The time interval between the deposition of the two formations seems to have been one in which gentle warping and tilting occurred. Only a small amount of erosion seems to have taken place between the Sisquoc and the Foxen in the deeper parts of the valley.

Sometime in Upper Pliocene (or late Middle Miocene ?) time, the Santa Maria Valley area was gently, but rapidly, depressed. The Foxen sea came in from the west, depositing successively younger and younger deposits eastward. In early upper Foxen time, the sea began to withdraw, leaving a shore-line sand behind. The nature of Foxen sediments and fauna suggests that the Foxen basin was merely a moderately deep depressed area, more or less isolated from the rest of the ocean on the west, and that this basin gradually filled to its top. Like the Monterey and Sisquoc, the Foxen also overlaps toward the north, and completely covers the Sisquoc, to rest directly on the "Franciscan." At the close of Foxen time, renewed gentle warping and tilting of the area took place. The Foxen was moderately eroded.

In late Pliocene, or early Pleistocene time, the adjacent land masses must have suffered rapid elevation and vigorous erosion, as evidenced by the coarse clastic composition of the Paso Robles formation, which lies on the Foxen. Whether these sediments were deposited under lacustrine and fluvial conditions, or whether deposition actually took place in cut-off arms of the old marine sea, is an open question.

After the deposition of the Paso Robles, the adjacent land masses must have again suffered rapid elevation and vigorous erosion, because of the extensive thickness of the so-called alluvium and stream gravels. However, the later formation was probably deposited under strictly continental conditions and its materials derived from a different source from that of the Paso Robles.

The warping of the valley, together with renewed faulting along the old Miocene structure lines, which accounts for the present accumulation of oil, probably culminated in late Pleistocene time.

Conclusion

From the foregoing pages on stratigraphy, structure, geologic history, and oil production, it is apparent that the Santa Maria Valley oil field is unique among the oil fields of California. Geologically, there is no other field exactly like it in the state. The disconformities in the Miocene are particularly noteworthy. The fact that wells are able to make more than 5,000 barrels of oil when the gravity and gas-oil ratio are so low, is indeed surprising.

The principal features of the Santa Maria Valley oil field may be briefly summarized as follows.

1. Location on north flank of the Santa Maria Valley syncline.
2. Overlap type of trap: Miocene laps northward over the "Franciscan," and buttresses against the overlying Sisquoc (late Pliocene).
3. Three thousand feet of closure on top of the Miocene: production coming from wells which top the Miocene with a difference of 3,000 feet in subsea elevation.
4. Production from the Miocene, both shales and sands.
5. Twenty-five to 10,000-barrel production of 16.5° gravity crude, with asphalt base, 4 per cent sulphur, 20 per cent gasoline and volatile constituents, and averaging 2 per cent water cut. Gas-oil ratio only 200:1.

From the standpoint of ultimate production, the Santa Maria Valley oil field will probably be one of the largest in California. An estimated total production of 500 million barrels is probably not too large to predict for the field.

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"PARK CITY" BEDS ON SOUTHWEST FLANK OF UINTA MOUNTAINS, UTAH[1]

J. STEWART WILLIAMS[2]
Logan, Utah

ABSTRACT

1. The "Park City formation" as defined by Boutwell is not a valid stratigraphic unit and the name should be abandoned.

2. Richards and Mansfield's terminology for the middle and upper members of the "Park City formation" may be extended from southeastern Idaho, these members constituting the Phosphoria formation.

3. The two members of the Phosphoria formation may be recognized as far toward the southeast as Ashley Creek, and the names Rex member and phosphatic shale member may be applied to them.

4. The phosphatic shale member contains no phosphate rock of commercial value, at least according to present-day standards, between Midway and Whiterocks River.

5. The Rex member east of the Duchesne River is found to interfinger with, and to be replaced by, "red beds" for which the name Mackentire "red-beds" tongue of the Phosphoria formation is proposed.

6. The lower member of the "Park City formation" thins eastward on the south flank of the Uinta Mountains and disappears beyond the Duchesne River. Eastward on the north flank it thickens, at least to the vicinity of Holiday Park, and its limestone content increases greatly.

7. The exact relationship of the lower member of the "Park City formation" to the Weber formation is not known because of the lack of data and a conflict in the observations already made. On the basis of essential lithologic character the writer is inclined to believe this lower member is merely a lithologic facies of the Weber formation. It may become the "Park City member of the Weber formation."

To the present, the only article dealing directly with the "Park City formation" in the Uinta Mountains is that of Schultz[3] who, in 1914, made a geologic reconnaissance, with special reference to phosphate, of that part of the range which lies in Utah. With only 6 weeks in which to circle the western two-thirds of the range and map the outcrops of the phosphate-bearing beds, Schultz collected a remarkable number of data including, in addition to much information on the structural geology, six detailed measurements of the "Park City formation," and thirty-seven samples of phosphate rock for analysis. He recognized[4] the necessarily cursory nature of his examination, however, and suggested the desirability of a more leisurely detailed study.

With interest in western phosphate deposits increasing, it seemed to the writer desirable to undertake a detailed study of the "Park City formation" in the Uinta Mountains, searching out all exposures

[1] Manuscript received, June 27, 1938.

[2] State Agricultural College, Department of Geology.

[3] A. R. Schultz, "A Geologic Reconnaissance of the Uinta Mountains, Northern Utah, with Special Reference to Phosphate," *U. S. Geol. Survey Bull. 690-E* (1919).

[4] *Ibid.*, p. 33.

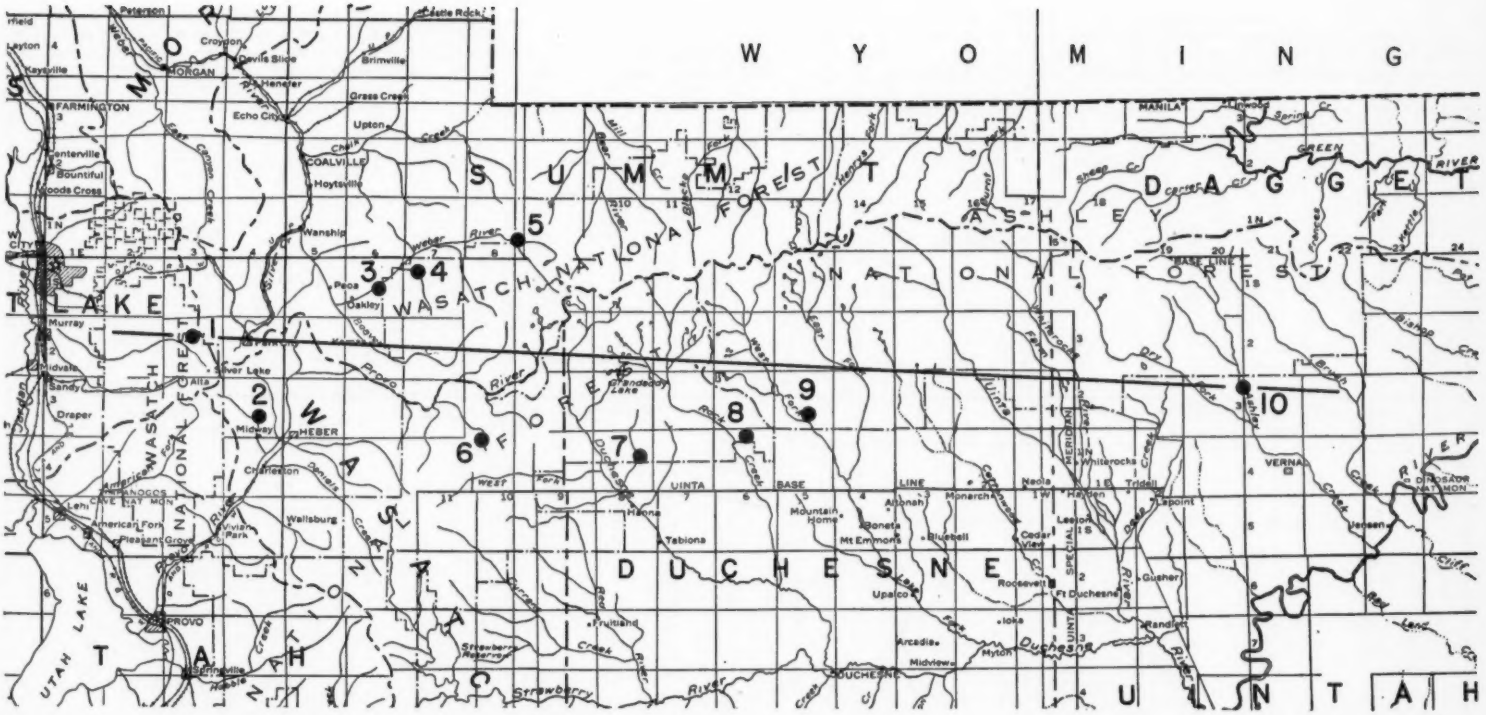

FIG. 1.—Index map of part of northeastern Utah showing the localities discussed, and the line, connecting type locality in Big Cottonwood Canyon with outcrop on Ashley Creek, on which positions of other localities are projected in diagrammatic section of Figure 2. 1. Big Cottonwood Canyon; 2. Midway; 3. Franson Canyon; 4. South Fork of Weber River; 5. Holiday Park; 6. South Fork of Provo River; 7. Blind Stream; 8. Dry Canyon; 9. West Fork of Lake Fork; 10. Ashley Creek.

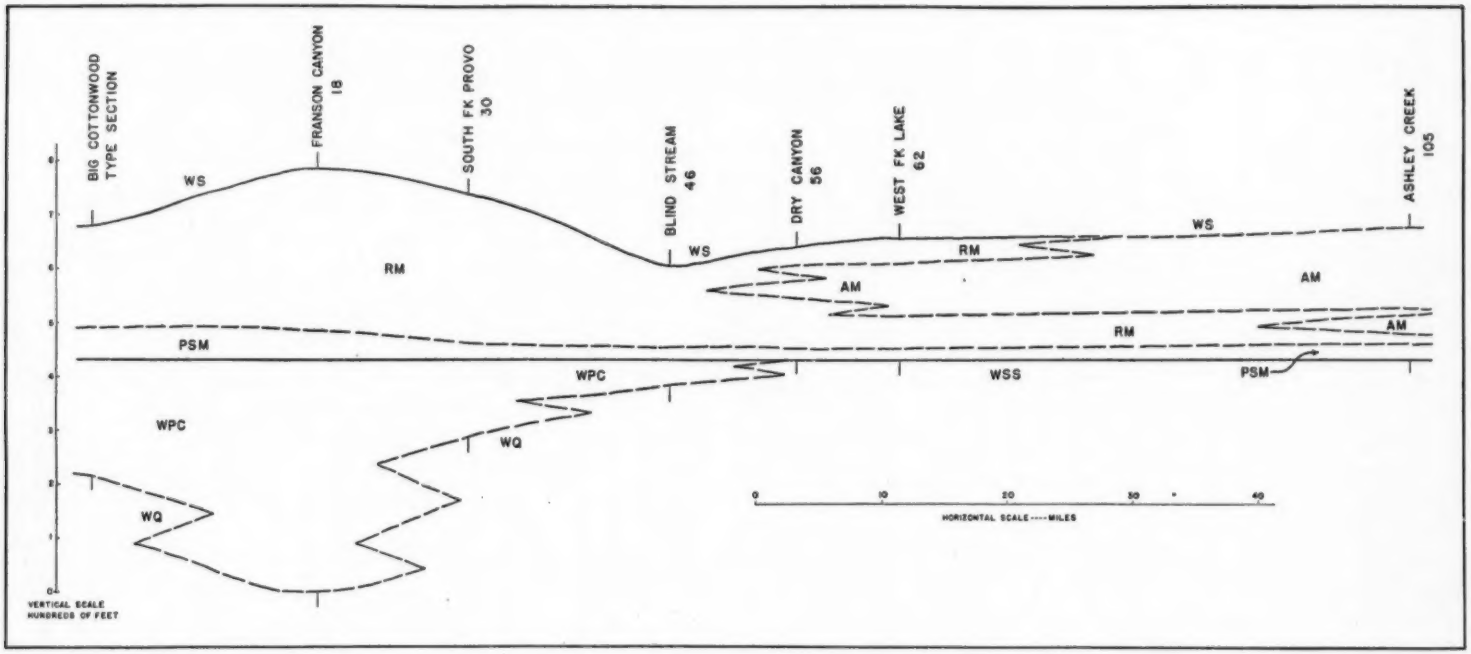

FIG. 2.—Diagrammatic section eastward along a line from Big Cottonwood Canyon, type section of "Park City formation" to Ashley Creek, Uinta County, Utah, showing general stratigraphic relations of members of Phosphoria formation and lower member of "Park City formation." Number with each locality is distance in miles of point of projection of locality on line from type section. WS, Woodside shale; RM, Rex member of the Phosphoria formation; PSM, phosphatic shale member of Phosphoria formation; AM, Mackentire "red-beds" tongue of Phosphoria formation; WPC, lower member of "Park City formation"; WSS, Weber sandstone; WQ, Weber quartzite.

not visited by Schultz, and determining if possible the origin of the fairly high-grade float reported by him and suggesting the possible presence of undiscovered beds of phosphate rock of commercial value. Accordingly, 6 weeks of the 1937 field season were spent in following the line of outcrop along the Weber and Provo rivers and eastward as far as Ashley Valley. Seven sections were measured in detail at points not visited by Schultz, or not described in detail by him, and the section north of Ashley Valley was remeasured. Fossils and lithologic samples were systematically collected in all sections. Time did not permit an examination of the formation east of Big Brush Creek, or along the north flank of the range on the drainage area of Blacks Fork and in the vicinity of Manila, Daggett County. Later, however, the writer had the opportunity to travel for 3 weeks over the western phosphate field and see the Phosphoria formation at many places in Wyoming, Montana, and Idaho. He has also examined the type section of the "Park City formation" in Big Cottonwood Canyon, the outcrop in lower Weber Canyon, and the Brazer-Wells-Phosphoria section in Brazer Canyon, Crawford Mountains, Utah.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the dependable and enthusiastic assistance of Hal Robinson of Fillmore, Utah, who served as field assistant throughout the study. He is indebted to George R. Mansfield of the United States Geological Survey for analysis of the phosphatic shale samples, and to Carl O. Dunbar of Yale University for critically reading the manuscript and offering valuable suggestions.

NOMENCLATURE

The "Park City formation" as defined by Boutwell[5] apparently is not a valid stratigraphic unit and the name applied in that sense is no longer useful. Soon after the extension of the use of the name into southeastern Idaho, Girty[6] discovered that the limestones below the phosphatic shale member were Pennsylvanian in age, and the phosphatic shales and the limestones above them contained Permian fossils. This caused a disruption of the "Park City formation," the lower member being included with the Pennsylvanian Wells formation, and the middle and upper members being grouped to form the Phosphoria formation. The three members just discussed retain their identity at the west end of the Uinta Mountains, and there likewise the same

[5] J. M. Boutwell, "Stratigraphy and Structure of the Park City Mining District, Utah," *Jour. Geology*, Vol. 15 (1907), pp. 434–58.

[6] G. H. Girty in G. R. Mansfield, "Geography, Geology, and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), pp. 78–79.

faunal distinction holds. Eastward on the south flank of the Uintas the upper and middle members persist at least as far as Ashley Valley, but the lower member thins and disappears, most probably by a lateral change of facies into the Weber sandstone, and beyond the Duchesne River the phosphatic shale member rests directly on the massive Weber sandstone. The name has no application south,[7] west,[8] or north of the type area except in lower Weber Canyon. Toward the north-northeast, in Brazer Canyon, where the three members of the "Park City" beds are recognizable above massive gray quartzite, apparently the equivalent of the Weber, Richardson[9] chose to extend the terminology from southeastern Idaho rather than to adopt Boutwell's name. In central Wyoming the general stratigraphic sequence of this section is similar to that in the central Wasatch Mountains, the phosphate-bearing series between the massive Pennsylvanian sandstone (Tensleep) and the Triassic "red beds" (Dinwoody) containing both Pennsylvanian and Permian faunas.[10] Condit[11] once applied the name "Park City" to the whole sequence, but later[12] used the term Phosphoria. More recently C. C. Branson[13] has used the name Phosphoria in the same way. Miller and Cline[14] have pointed out the undesirability of extending the term to include the Pennsylvanian member of the sequence, thus bringing beds belonging to two different systems into one formation.

Near Holiday Park on the upper Weber River the writer collected a Pennsylvanian faunule from the upper part of the lower member of the "Park City formation" containing *Spirifer occidentalis* Girty, a representative of a type of *Spirifer* that does not range above the Fort Scott limestone of the Des Moines series in the Mid Continent

[7] A. J. Eardley, "Stratigraphy of the Southern Wasatch Mountains, Utah," *Papers Michigan Acad. Sci., Arts and Letters*, Vol. 18 (1932), pp. 322–24.

[8] J. Gilluly, "Geology and Ore Deposits of the Stockton and Fairfield Quadrangles, Utah," *U. S. Geol. Survey Prof. Paper 173* (1932), pp. 34–38.
T. B. Nolan, "The Gold Hill Mining District, Utah," *U. S. Geol. Survey Prof. Paper 177* (1935), pp. 39–42.

[9] G. B. Richardson, "The Paleozoic Section in Northern Utah," *Amer. Jour. Sci.* Ser. 4, Vol. 36 (1913), pp. 414–15.

[10] E. B. Branson, "The Lower Embar of Wyoming and Its Fauna," *Jour. Geology*, Vol. 24 (1916), pp. 639–64.

[11] D. D. Condit, "Relations of the Embar and Chugwater Formations in Central Wyoming," *U. S. Geol. Survey Prof. Paper 98-O* (1916), pp. 263–70.

[12] *Idem*, "Phosphate Deposits in the Wind River Mountains near Lander, Wyoming," *U. S. Geol. Survey Bull. 764* (1924), pp. 11–13.

[13] C. C. Branson, "Paleontology and Stratigraphy of the Phosphoria Formation," *Univ. Missouri Studies*, Vol. 5, No. 2 (1930), pp. 20–21.

[14] A. K. Miller and L. M. Cline, "The Cephalopods of the Phosphoria Formation of the Northwestern United States," *Jour. Paleon.*, Vol. 8 (1934), pp. 281–302.

region. This indicates that the lower member of the "Park City formation" is Lower Pennsylvanian in age. The age of the middle member is apparently Middle Permian.[14a] On the basis of such faunal evidence it is imperative that the "Park City formation" be divided. Furthermore, the base of the phosphatic shale member serves as a completely persistent, readily recognized boundary between the rocks of the two systems in the area covered by this study, as it does in Idaho. It is proposed, then, to extend the terminology from southeastern Idaho to the middle and upper members of the "Park City formation," and to restrict the term "Park City" to the lower or Pennsylvanian member.

If it can be demonstrated that the lower member is separated from the underlying Weber by an important unconformity, such as reported by Blackwelder,[15] it may be desirable to retain for it the name "Park City formation"; if, on the other hand, it is merely a lithologic facies of the Weber-Morgan-Wells group, as believed at present by the writer, it may in fact become the "Park City member of the Weber formation." The final disposition of this member must await a complete unravelling of the stratigraphy of the Pennsylvanian rocks of the region.

PHOSPHATIC SHALE MEMBER OF PHOSPHORIA FORMATION

From a thickness of 50 feet at Franson Canyon (Fig. 3) and perhaps slightly more at Big Cottonwood, the phosphatic shale member thins gradually to 20 feet on Blind Stream, a thickness which it maintains to Ashley Creek. It contains little high-grade phosphate rock. In the Park City district the basal 3–4 feet is oölitic and averages 25–35 per cent P_2O_5, but from Franson Canyon to Whiterocks River there are only here and there thin discontinuous stringers of oölitic rock. The entire shale zone (50 feet) at Franson Canyon averaged only 8.63 per cent P_2O_5 and on Blind Stream 12 feet of the zone tested only 2.95 per cent P_2O_5. At Whiterocks River the basal oölitic beds reappear[16] and north of Ashley Valley fairly high-grade rock is scattered throughout the whole 20 feet of the zone. It can be stated with confidence that from Franson Canyon to the West Fork of Lake Fork there are no phosphate beds of any commercial value according to present standards.

The phosphatic shales are nonfossiliferous with few exceptions.

[14a] A. K. Miller and L. M. Cline, *op. cit.*

[15] Eliot Blackwelder, "New Light on the Geology of the Wasatch Mountains, Utah," *Bull. Geol. Soc. America*, Vol. 21 (1910), pp. 532–33.

[16] A. R. Schultz, *op. cit.*, p. 51.

In the vicinity of Franson Canyon a 6-inch basal bed is composed almost entirely of the casts of small pelecypod and snail shells. The depauperate faunule includes the following.

Orbiculoidea sp.
Dielasma (?) sp.
Nucula sp.
Yoldia mcchesneyana Girty (plentiful)
Leda bellistriata Stevens (common)
Pleurophorus sp.
Schizodus (?) sp.
Schizodus ferrieri Girty
Plagioglypta canna White
Pleurotomaria phosphaticus C. Branson (plentiful)
Pleurotomaria aff. *P. nevadensis* Walcott
Omphalotrochus sp.
Microdoma (?) sp.
Naticopsis sp.
Ostracod indet.

FIG. 3.—View northward across the mouth of Franson Canyon into mouth of upper Weber Canyon, Coalville Quadrangle, Utah. In ridge between canyons may be seen light-colored Phosphoria formation overlain by red Woodside shale. Ridge beyond Weber Canyon is capped by "Nugget sandstone."

Thin seams of oölitic rock are almost invariably crowded with the casts of shells of these small clams and snails, particularly *Y. mcchesneyana*, *L. bellistriata*, and *P. phosphaticus*. The brownish black phosphatic shales in all sections include a few beds of fetid, medium gray, fine-grained sandstone ranging from a few inches to 2 feet thick.

At every outcrop where the top of the phosphatic shales is exposed, they are seen to grade upward into greenish gray shales and thin-bedded sandstones. The shales and sandstones are invariably cherty, the chert occurring as flattened nodules and lenses thickly set along the bedding planes. The unique color and nodular bedding of these rocks are striking, and these features, together with their uniformity, their continuity along the strike, and their position immediately above the phosphatic shales, make them a valuable horizon marker. They

were so recognized by Schultz,[17] and Condit has so used them in central Wyoming.[18] Although they are weaker beds and constitute a part of the shaly phase of the formation, at least in their lower part, they are readily distinguished from the black phosphatic shales below, and are hence considered a part of the Rex member. They mark the lowest development of chert which is conspicuous in the limestones and calcareous sandstones of the rocks above them.

There is little organic matter in the phosphatic shale zone in the vicinity of Ashley Creek, and as a result the predominant color of the rocks is greenish light gray rather than black or sepia-brown as at most other localities in the western field. Phosphate oölites, of medium to large grain size, and phosphate casts of small clam and snail shells are scattered in all degrees of concentration through 20 feet of clastic sediments. The resulting rocks range from almost pure phosphate oölites through phosphatic sandstones to slightly phosphatic siltstones and shales with thinly scattered oölites. The phosphatic beds merge upward into light gray siltstones and shales, part of the Mackentire "red-beds" tongue, to be described shortly.

REX MEMBER OF PHOSPHORIA FORMATION

The beds between the green cherty shale and the Triassic Woodside shale are principally calcareous sandstone with some limestone, quartzite, and shale. Chert is plentiful everywhere. Beds of medium gray limestone are conspicuous at the top of the section in Big Cottonwood and Franson canyons, and on the South Fork of the Provo River, but they thin toward the southeast and disappear beyond the Duchesne River. From that point to Ashley Creek the member is represented by yellowish light gray calcareous sandstones. *Punctospirifer pulchra* was found only in the limestones.

In the canyon of the South Fork of the Weber River there is 55 feet of medium to light gray dense limestone. From it the following fossils were collected.

Batostomella sp.
Orbiculoidea utahensis Meek
Juresania (?) sp.
Dielasma cf. *D. phosphoriensis* C. Branson
Spirifer aff. *S. cameratus* Morton
Punctospirifer pulchra (Meek)
Punctospirifer kentuckyensis (Shumard) (?)
Composita cf. *C. parva* C. Branson
Aviculopecten sp. A
Aviculopecten sp. B
Myalina sp.
Lima (?) sp.
Fish remains

This faunule clearly represents the *Punctospirifer pulchra* fauna that characterizes the Rex chert member of the Phosphoria formation in

[17] *Op. cit.*, p. 47.

[18] D. D. Condit, "Relations of the Embar and Chugwater Formations in Central Wyoming," *op. cit.*, pp. 264 and 266.

southeastern Idaho.[19] It appears to have more species in common with the "*Hustedia* faunule" than any other of the four described by C. C. Branson.[20]

In the vicinity of Ashley Creek the following faunule was collected from a calcareous sandstone tongue of the Rex member about 30 feet above the phosphatic shale zone and about 50 feet above the base of the formation.

Edmondia phosphatica Girty
Nucula montpelierensis Girty
Leda obesa White
Leda (?) sp.
Schizodus sp.
Aviculopecten montpelierensis Girty
Aviculopecten cf. *A. alternatus* C. C. Branson
Pleurophorus sp. A
Pleurophorus sp. B
Pleurophorus sp. C
Bucanopsis sp.
Pleurotomaria sp. A
Pleurotomaria sp. B
Plagioglypta canna White
Coelogastroceras cf. *C. thomasi* Miller and Cline
Fish remains (?)

The fossils occur as plentiful shell fragments in a thin bed of platy sandstone. The fragmental nature of all the remains, and the predominance of pelecypods in the faunule suggest a littoral environment of deposition. However, *E. phosphatica*, *N. montpelierensis*, and *A. montpelierensis* are all from the "Cap lime" just above the phosphatic shale zone in southeastern Idaho,[21] and *A. alternatus* occurs in the *Hustedia* member which occupies the same position relative to the principal phosphate bed in central Wyoming. *Coelogastroceras thomasi* occurs[22] in the "Top Limestone member" of the Phosphoria formation in association with *Punctospirifer pulchra* (Meek). There can be little doubt that this faunule represents the horizon of the *Punctospirifer pulchra* fauna.

Orbiculoidea utahensis Meek is common in this member. It seems to be most plentiful in the calcareous sandstones in the lower part, not far above the green shale.

The calcareous sandstones of this member are commonly cherty. At Franson Canyon there are 70 feet of beds which are at least 50 per cent chert. Cherty beds of about equal thickness are present on the South Fork of the Provo, and white chert is plentiful in the calcareous sandstones at Blind Stream, Dry Canyon, and the West Fork of Lake Fork. As chert is extremely common throughout the Paleozoic section in northern Utah it is probable that no particular significance can be attached to its commonness at this horizon. This

[19] G. H. Girty, *op. cit.*

[20] *Op. cit.*, pp. 18–20.

[21] G. H. Girty, "The Fauna of the Phosphate Beds of the Park City Formation in Idaho, Wyoming, and Utah," *U. S. Geol. Survey Bull. 436* (1910).

[22] Miller and Cline, *op. cit.*, p. 287.

lithologic feature does not detract, however, from a correlation with the Rex chert of southeastern Idaho.

The Rex member is thickest (355 feet) at Franson Canyon and thinnest (150 feet) on Blind Stream. Ten miles farther east in Dry Canyon it has begun to interfinger with the "red beds" of the Mackentire tongue, and from there eastward it grows progressively thinner by the replacement of successively lower units until at Ashley Creek its uppermost tongue is only 100 feet above the Weber formation.

FIG. 4.—View eastward in Sec. 27, T. 2 N., R. 5 W., Uinta base and meridian, on West Fork of Lake Fork to the mouth of Mackentire Draw (coming in from left). Steeply dipping light-colored bed on left is an upper tongue of Rex member of Phosphoria formation, and is underlain by nearly 100 feet of "red beds" of Mackentire tongue, visible just above dip slope that extends toward left foreground. The dip slope is formed on a lower tongue of Rex member. Light-colored bed above unconformity is Bishop (?) conglomerate.

MACKENTIRE "RED-BEDS" TONGUE OF PHOSPHORIA FORMATION

Concomitantly with the thinning of the Rex member, gray and red sandstones, siltstones, and shales appear between the calcareous sandstones and the main body of the Woodside shale. No such beds are present in the Blind Stream section but 10 miles eastward in Dry Canyon they are an estimated 100 feet thick. At West Fork of Lake Fork above the phosphatic shale member there are 95 feet of brick-red and lavender sandstones and shales between two 50-foot units of yellowish light gray calcareous sandstone (Fig. 4). The upper unit is considered an eastwardly thinning tongue of the Rex member, the intermediate red beds a westwardly thinning tongue of the "red beds."

In the vicinity of Ashley Creek (Figs. 5 and 6) the lower part of the Phosphoria formation consists of two shaly units of about equal

FIG. 5.—Mouth of gorge on Ashley Creek, Uinta County, Utah, showing lower 95 feet of Phosphoria formation resting on Weber sandstone. Lower half of lower shaly interval is phosphatic shale member of Phosphoria formation.

FIG. 6.—Lower 95 feet of Phosphoria formation on tributary to Little Brush Creek, Uinta County, Utah. Below is massive Weber sandstone. Resistant beds of platy sandstone between shaly zones contain *Punctospirifer pulchra* fauna. Upper shaly zone and upper half of lower zone are gray shales and siltstones of Mackentire "red-beds" tongue of Phosphoria formation.

thickness each capped by more resistant calcareous sandstone. The lower unit is 30 feet of phosphatic and green shales overlain by 10 feet of gray siltstone identically like that occurring in the "red beds"

above. The capping layer is calcareous sandstone and contains the fauna already listed. It is clearly a tongue of the Rex member from the west. The upper unit comprises 35 feet of gray siltstone grading upward into a 10-foot capping layer of calcareous sandstone. Above this there are 150 feet of gray and red sandstones, siltstones, and shales below the main body of the Woodside red shale. At this point, then, the red and gray shales, interfingering from the east, have almost entirely replaced the calcareous sandstone facies from the west.

Schultz[23] recognized the greater thickness of the upper shaly beds in this vicinity and noted a limited resemblance between them and the Dinwoody formation on the east side of the Wind River Mountains. The writer has not seen the Dinwoody formation, but from the reports of others[24] it appears that in lithologic character it resembles, at least in a general way, these gray and red sandstones, siltstones, and shales that constitute most of the Phosphoria section in this region. Whether the Dinwoody is Triassic or Permian is apparently not known. Although these beds may represent substantially the same conditions of deposition as the Dinwoody, they here interfinger with, rather than lie on, beds of calcareous sandstone containing the *Punctospirifer pulchra* fauna of the Rex member of the Phosphoria formation, and hence are the time equivalent of the upper part of that formation.[25] They represent a unit of deposition in which there is no apparent break below the main body of the Woodside shale. The writer proposes to designate these beds the Mackentire "red-beds" tongue of the Phosphoria formation, from their development at the mouth of Mackentire Draw, a small tributary of the West Fork of Lake Fork in Sec. 27, T. 2 N., R. 5 W., Uinta Base and Meridian (Fig. 4).

LOWER MEMBER OF "PARK CITY FORMATION"

The beds between the phosphatic shale member and the main body of the massive Weber quartzite from Big Cottonwood Canyon eastward to the Duchesne River consist of sandstone, calcareous sandstone, quartzitic sandstone, and quartzite with only minor amounts of limestone. The quartzite is dense gray rock closely resembling that in the main body below, and in places occurring in units 30–50 feet thick. The beds as a whole are much less resistant to erosion than the main body of quartzite, however, and are therefore readily distinguishable in the field. They are generally but sparsely fossiliferous, the only fossils obtained by the writer being a few

[23] *Op. cit.*, p. 47.

[24] Condit, *op. cit.* (1916 and 1924); C. C. Branson, *op. cit.* (1930).

[25] See also G. R. Mansfield, "Geography, Geology, and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), p. 373.

specimens of *Schizodus* preserved as molds in a sandstone bed on the South Fork of the Provo River.

The beds which constitute this member are 440 feet thick in Franson Canyon, and 225 feet in the type section.[26] Eastward, on a tributary to the South Fork of the Provo River they have thinned to 190 feet, and on Blind Stream, just east of the Duchesne River, to 50 feet. East of this locality they disappear entirely and the phosphatic shales come to rest directly on the massive Weber sandstone. Fifteen miles east-northeast of the Franson Canyon locality, along the Weber River, these beds are greatly thickened, apparently, at least in part, at the expense of the underlying quartzite, and much changed by a great increase in the proportion of limestone. Schultz[27] has measured them in three sections on the northeast flank of the range where they vary from 100 to 400 feet in thickness. This member then is absent east of the Duchesne River on the south flank of the range, present on the northeast flank in moderate thickness, present in great thickness near the head of Weber Canyon, and present in moderate thickness in the vicinity of the type section in the central Wasatch Mountains.

In the ledges above Holiday Park the member consists of hundreds of feet of beds, mostly of medium gray limestone with many fossils. From a horizon estimated to be about 200 feet below the top of the member the following fossils were collected.

Fenestella sp.
Menophyllum sp.
Syringopora cf. *S. occidentalis* H. and W.
Derbya sp.
Chonetes sp.
Avonia sp.
Dictyoclostus sp.
Dictyoclostus coloradoensis (Girty)
Echinoconchus sp.
Juresania sp.
Juresania sp.
Linoproductus sp.
Linoproductus sp.
Rhynchophora sp.
Dielasma sp.
Spirifer occidentalis Girty
Punctospirifer cf. *P. spinosa* (Norwood and Pratten)
Cleiothyrinda orbicularis McChesney
Squamularia (?) *perplexa* (McChesney)
Composita subtilita Hall
Aviculopecten sp.
Aviculopecten sp.
Euomphalus sp.

There can be little doubt that this faunule is of Pennsylvanian age despite the fact that the fragmentary nature of the material has made specific identification impossible for most forms. It contains no species characteristic of either member of the Phosphoria formation. In fact, as *S. occidentalis* does not range above the Fort Scott limestone in the Mid-Continent region[28] the faunule apparently is Lower Pennsylvanian.

[26] Boutwell in Schultz, *op. cit.*, pp. 49–50.

[27] *Op. cit.*, pp. 52–53.

[28] C. O. Dunbar and G. E. Condra, "Brachiopods of the Pennsylvanian System in Nebraska," *Nebraska Geol. Survey Bull.* 5 (1932), pp. 325–26.

RELATIONSHIP OF LOWER MEMBER OF "PARK CITY FORMATION" TO WEBER FORMATION

The foregoing described thickening and thinning of the lower member of the "Park City formation" was taken by Schultz[29] to indicate an unconformity at the base of the formation. This interpretation must have been arrived at on the conception that deposition of the lower member began in separate basins or depressions in a surface eroded in the underlying Weber formation and that the sea did not completely cover the area until the beginning of the deposition of the middle or phosphatic shale member, which is continuous over the area. Richards and Mansfield[30] observed an unconformity between the phosphatic shale member and the lower member of the "Park City formation" and used that structural evidence, together with the faunal evidence, to justify a disruption of Boutwell's formation. But the stratigraphic break they observed is between the phosphatic shale member and the lower member of the "Park City formation," not at the base of said formation. Blackwelder[31] has reported an obscure unconformity and a basal breccia at the base of the "Park City formation" in the vicinity of Weber Canyon and in Cottonwood Canyon, but this is not at the same horizon as that reported by Richards and Mansfield—it is below the lower member of the "Park City formation," that is, at the top of the Weber formation.

In the Wind River and Owl Creek mountains, according to C. C. Branson,[32] the "Phosphoria formation," including a Pennsylvanian fauna at the bottom grading into a Permian fauna at the top, without a faunal or structural break, lies unconformably on the underlying Tensleep sandstone. In other words, stratigraphic breaks are reported for both the top and the bottom of the lower member of the "Park City formation" in different parts of the area it covers.

The presence of a break at the top of the lower member is required by the faunal evidence and supported by the strong contrast in lithologic character between the lower and middle members, as has been pointed out. The writer has no direct evidence to contribute on the question of an unconformity at the base of the lower member. He did not have an opportunity to observe carefully the contact between the lower member and the Weber. From the close similarity between the two, however, he is inclined to believe the lower member simply a

[29] *Op. cit.*, pp. 48–53.

[30] R. W. Richards and G. R. Mansfield, "Geology of Phosphate Deposits Northeast of Georgetown, Idaho," *U. S. Geol. Survey Bull. 577* (1914), pp. 18–22.

[31] Eliot Blackwelder, *op. cit.*, pp. 532–33.

[32] *Op. cit.*, p. 8.

more calcareous facies of the Weber deposition, and to consider the thinning and disappearance of the lower member toward the southeast as due merely to a lateral change of facies into the main body of Weber sandstone and quartzite. If this suggested relationship is true, any widespread unconformity of considerable significance is not to be expected at the base of this member which becomes merely a member of the Weber formation. On the other hand, if such an unconformity as described by Blackwelder[33] exists between the lower member of the "Park City formation" and the Weber, it is necessary to regard the lower member as a distinct formation. If its limestone content relates it to the Wells type of sedimentation, it may even prove to be a southward extending tongue of the Wells formation.

BOUNDARY BETWEEN PHOSPHORIA AND WOODSIDE FORMATIONS

At Big Cottonwood and Franson canyons and as far east as Blind Stream, the main body of red Woodside shale rests directly on the light gray limestones and calcareous sandstones of the Rex member of the Phosphoria formation. The change is abrupt and striking, even more so perhaps than in southeastern Idaho where the Woodside has a greenish gray color. No irregularity suggesting an erosion surface was observed at the top of the Phosphoria and no basal conglomerate was found. No fossils were found in the lower parts of the Woodside, but presumably here, as in southeastern Idaho,[34] the striking lithologic change is matched by a corresponding faunal change. The rather considerable changes in thickness of the Rex member in the region may also be evidence for a disconformity of considerable magnitude at the top of the Phosphoria formation.

East of Blind Stream where the Mackentire "red-beds" tongue overlies and interfingers with the calcareous sandstones of the Rex member, the boundary between the two formations is no longer so distinct. Megascopically, there is no essential and constant difference between the red shales and sandstones of the Mackentire tongue and those that constitute the main body of the Woodside shale. The boundary has been placed arbitrarily at the top of the highest bed of gray shale. Farther east even that distinction may disappear.

The presence of the *Punctospirifer* fauna in a tongue of calcareous sandstone interfingering with the "red beds" is evidence of the contemporaneous deposition of such beds toward the east while the limestone facies of the Rex member of the Phosphoria was being deposited toward the north and west. Conditions here were apparently

[33] *Op. cit.*

[34] G. R. Mansfield, *op. cit.*, pp. 84–85.

the same as in central Wyoming where Condit,[35] with the aid of the persistent green chert bed that overlies the phosphatic shale zone, was able to trace the limestone facies of the Phosphoria into "red-beds." The writer has so far been unable to discover evidence of a physical break between the Mackentire tongue and the Woodside but further search toward the south and east may reveal one. On the other hand it may be that "red-bed" deposition was continuous in the region south and east of Ashley Creek, and that the disconformity dies out in that direction.

SECTION AT MOUTH OF FRANSON CANYON

NE. ¼, Sec. 22, T. 1 S., R. 6 E., Salt Lake Base and Meridian

	Thickness in Feet
Woodside Shale	
Phosphoria Formation	
Rex Member	
Pinkish light gray, siliceous limestone weathering white	25
Bluish medium gray, dense- to medium-grained sandstone with roundish nodules of red chert	25
Dense, medium gray, siliceous rock. Medium- to fine-grained, calcareous sandstone	40
Thin-bedded, light gray quartzite and medium- to fine-grained, calcareous sandstone weathering buff or white	30
Thin-bedded, medium gray, medium-grained sandstone and arenaceous shale weathering greenish gray. Some green chert	25
Porous, gray quartzite and buff-weathering, light gray, medium-grained calcareous sandstone	15
Very cherty light gray, medium- to fine-grained, calcareous sandstone weathering buff. Chert in thin continuous stringers as thick as 2 inches	55
Yellowish light gray, fine-grained, calcareous sandstone. Comparatively soft, making a covered slope	22
Yellowish light gray to white, siliceous limestone with fragmental texture and showing bits of corneous shell fragments	20
Greenish medium gray, siliceous shale with medium to light gray chert nodules coated green	11
Massive bed of finely divided chert about 80 per cent small irregular chert masses and 20 per cent calcareous cement	8
Greenish medium gray, siliceous shale	11
Medium gray, dense quartzite with much chert disseminated throughout in small irregular masses. Beds 1 foot thick	6
Green, siliceous shale grading downward into black shale of phosphate shale member	12
Phosphatic Shale Member	
Dark brown to black shale with some beds, from 4 inches to 2 feet thick, of fine-grained, dark brown sandstone. Toward top the shale becomes siliceous, grading upward into green siliceous shales	50
Total	355
Weber Formation (?)	
Lower Member of "Park City Formation"	
Gray, dense quartzite in beds 4 inches to 2 feet thick. Considerable white chert in lenses, stringers and irregular masses	45
Dense, gray quartzite, gray quartzitic sandstone, and medium-grained dirty gray fetid limestone	395
Total	440
Weber Quartzite	

[35] D. D. Condit, "Relations of the Embar and Chugwater Formations in Central Wyoming," *op. cit.*, pp. 263–70.

SECTION ON BLIND STREAM ABOVE HANNA, UTAH

Sec. 14, T. 1 N., R. 8 W., Uinta Base and Meridian

Measured along Forest Service trail up east wall of the valley

	Thickness in Feet
Woodside Shale	
Phosphoria Formation	
Rex Member	
Yellowish light gray, medium- to fine-grained sandstone with fragments of corneous shells in lower part, thin-bedded in upper part	110
Nodularly bedded, cherty, green siliceous shale merging downward into black phosphatic shale	40
Phosphatic Shale Member	
Black, phosphatic shale with thin seams of oölitic phosphate rock and dense, dark gray sandstone	30
Total	180
Weber Formation (?)	
Lower Member of "Park City Formation"	
Light gray to buff, medium- to fine-grained sandstone, sandy gray limestone, and gray quartzite. Thickness estimated	50
Main Body of Weber Sandstone	

SECTION NORTH OF VERNAL, UTAH

Lower 95 feet measured at east side of mouth of gorge on Ashley Creek, Sec. 12, T. 3 S., R. 20 E., Salt Lake Base and Meridian

Upper 150 feet measured in Sec. 4, T. 3 S., R. 21 E., approximately ½ mile east of road to Taylor Mountain

	Thickness in Feet
Main Body of Red Woodside Shale	
Break?	
Phosphoria Formation	
Mackentire "Red-Beds" Tongue	
Alternating beds of gray and brick-red shale	25
Gray shale capped by thin, platy, gray limestone	25
Brick-red shale	25
Gray shale with thin nodules of black chert	75
Interfingering of Rex Member and Mackentire Tongue	
Light gray to white, calcareous siltstone and sandstone in beds about 1 foot thick	10
Light gray to white and faintly greenish shaly siltstone	20
Fine-grained sandstone and siltstone weathering light brownish yellow	15
Medium-grained, poorly cemented sandstone in beds as thick as 1 foot, weathering light gray or buff	10
White, calcareous siltstone in beds as thick as 1½ feet, some beds weathering light greenish gray	10
Phosphatic Shale Member	
Phosphatic shale and sandstone	30
Total	245
Weber Sandstone	

SECTION ON TRIBUTARY OF SOUTH FORK OF PROVO RIVER

SE. ¼, Sec. 31, unsurveyed, T. 3 S., R. 8 E., Salt Lake Base and Meridian

	Thickness in Feet
Woodside Shale	
Phosphoria Formation	
Rex Member	
Thin-bedded, cherty, sandy limestone and calcareous sandstone	20
Thin- to medium-bedded, light gray quartzite and calcareous sandstone with much white chert in lower part	150
Covered	20
Thin-bedded, cherty, argillaceous sandstone, light gray to buff and weathering buff. Chert medium to light gray, some coated green, and distributed thickly throughout beds. Lower 3 feet are olive-green, nodularly thin-bedded sandstone merging downward into green shale (In lower 6 feet are two thin seams of oölitic phosphate rock)	70
Covered (Rex member in part)	10
Phosphatic Shale Member	
Covered	30
(Total covered interval 40 feet. Distribution between two members estimated)	30
Total	330
Weber Formation (?)	
Lower Member of "Park City Formation"	
Massive- to medium-bedded, pure white to pinkish light gray, medium-grained, saccharoidal sandstone weathering white or pinkish, light brown, *et cetera*	45
Thin- to medium-bedded, light to medium gray, calcareous sandstone and siliceous limestone with bands of white opaque chert. Beds weather light gray to white	45
Covered. Interval to main body of Weber quartzite estimated	100
Total	190
Weber Quartzite	

SECTION IN DRY CANYON

SW. ¼, Sec. 3, T. 1 N., R. 6 W., Uinta Base and Meridian

	Thickness in Feet
Measured 1 mile east of Rock Creek at the Wasatch National Forest	
Woodside Shale	
Phosphoria Formation	
Interfingering of Rex Member and Mackentire Tongue (?)	
Alternating beds of red shale and gray shale (and calcareous sandstone?) Thickness estimated	100
Rex Member	
Yellowish light gray, calcareous sandstone with much light chert uniformly disseminated throughout. Thin-bedded	15
Massive, yellowish light gray, calcareous sandstone or sandy limestone with considerable chert	30
Pale greenish light gray, medium- to thin-bedded shaly sandstone and sandy shale with elongate chert nodules distributed throughout, covered below	10
Covered	30
Phosphatic Shale Member	
Covered interval showing some pieces of oölitic phosphate rock	20
Total	205
Weber Sandstone and Quartzite	

SECTION ON WEST FORK OF LAKE FORK

Sec. 27, T. 2 N., R. 5 W., Uinta Base and Meridian

	Thickness in Feet
Measured about 1 mile east of Rowley's Ranch	
Woodside Shale	
Phosphoria Formation	
Part of Rex Member	
Light gray, fine-grained, calcareous sandstone weathering light yellowish gray, with much chert. Lower half thin-bedded, upper half massive and about 50 per cent white chert in thin stringers. Calcite geodes plentiful	50
Mackentire "Red-Beds" Tongue	
Lavender, sandy shale and sandstone with considerable white chert	25
Earthy, dark brick-red, fine-grained sandstone and sandy shale	70
Part of Rex Member	
Yellowish light gray, calcareous sandstone in beds about 1 foot thick, some of the sandstone showing cross bedding	15
Massive yellowish light gray, cherty limestone, chert more than 50 per cent of rock, and uniformly distributed in small irregular masses. Weathers to greenish yellow (see Schultz)	5
Massive, yellowish light gray "rotten limestone" with shadows of many shells	5
Covered	20
Dense, fine-grained, greenish light gray sandstone and chert in thin nodular beds	10
Phosphatic Shale Member	
Black, phosphatic shale weathering light bluish gray or dull light gray interrupted by several beds of medium gray, fine-grained sandstone about 1 foot thick	20
Total	220
Weber Sandstone	
Medium- to coarse-grained, bituminous sandstone	10
Typical Weber sandstone	

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GEOLOGICAL NOTES

TEST ON AGATE ANTICLINE, NORTHWESTERN NEBRASKA[1]

EARL B. NOBLE[2]
Los Angeles, California

The Union Oil Company's Agate No. 15–1 is located 990 feet north and 990 feet west of the southeast corner of Sec. 15, T. 28 N., R. 55 W., Sioux County, Nebraska. It is on an east-west trending fold which can be mapped by running elevations on the Agate limestone, a 2–5-foot fresh-water bed at the top of the lower Harrison (Miocene). Surface dips are gentle, varying from 1° to 3°.

The well was spudded, April 25, 1938, and was drilled to a total depth of 6,846 feet. However, while reaming at 6,810 feet the drill pipe parted and after an unsuccessful fishing job the hole was re-drilled from 4,375 to 5,002 feet, at which depth drilling was suspended.

Ditch samples were collected at 5-foot intervals with intermittent coring from 4,639 to 6,325 feet, and continuous coring from 6,325 feet to bottom.

The following points were determined either from ditch samples or from cores. Depths given are measured from the top of the rotary table, elevation 4,705 feet.

Depth in Feet	
0–18	Upper Harrison—brown silty sands
80	Lower Harrison—fine gray sandstone with considerable ash
880	Monroe Creek and Brule—fine gray sand and light tan clay
960	Chadron—maroon, gray, blue and pink variegated clay shale
1,005	Pierre (Rusty member)—olive-green gritty shale
3,660	Pierre (typical)—bluish gray shale, minor amounts of tan-colored shale; slate-colored shale below 3,485 feet
3,930	Niobrara—black to slate-colored shale, slightly limy with Niobrara "speckle"
4,275	Carlile—black to slate-colored shale with small amount of limy sandstone
4,935	Greenhorn and Graneros—*Inoceramus* prisms at 4,275 feet, dark gray shale with fish scales
4,995	Dakota—fine sand and interbedded shale, worm borings
5,040	Fuson—green and purple shale
5,055	Minnewaste—white lime
5,156	Lakota—fine massive gray to green sand
5,285	Morrison—limy gray sand and variegated shale. (Note: driller recorded sand break at 5,240 feet, which may be top of Sundance)
5,409	Sundance—fine, friable, light gray sand
5,785	Spearfish—brick red, sandy shale and anhydrite
5,825	Minnekata—pink limestone
5,879	Opeche—red sandy shale and anhydrite

[1] Manuscript received, November 14, 1938.

[2] Chief geologist, Union Oil Company of California.

6,846 Minnelusa? This point has been under considerable discussion. Some geologists feel that the anhydrite section may be correlated with the Kansas Permian Big Blue group and may represent extra section not present in the Hartville uplift or the Black Hills. We have called everything Minnelusa from 5,879 feet to bottom. This interval consists of anhydrite and salt, a few pink quartzitic sands, dark limy shales, and dolomitic limestones. Several very pure beds of salt were cored, varying in thickness from 20 to 40 feet. First bed of pure salt cored was at 5,890 feet. A few slight oil cuts were obtained from dense dolomitic limestone below 6,363 feet. We feel the well did not reach the Madison limestone.

Note: The foregoing points were picked by C. L. Lee, resident geologist at the well. Horace D. Thomas, of the University of Wyoming, acted as consultant, and E. C.Reed, assistant State geologist of Nebraska, rendered valuable assistance.

DISCUSSION

ANTHONY FOLGER, Gulf Oil Corporation, Wichita, Kansas (discussion received, November 29, 1938). A complete set of samples of Union Oil Company of California's Agate No. 15–1, Sec. 15, T. 28 N., R. 55 W., Nebraska, was made available to the Gulf Oil Corporation for study by the Union. In addition to this, the complete suite of sixty-seven cores of this test was examined at the Union Oil Company's field office at the well. Both the drill cuttings and cores were studied by R. A. Carmody, Gulf microscopist, in the Wichita office. In addition to this, several members of this department, including Mr. Carmody, made a careful examination of the surface outcrops of the Hartville formation in the Hartville area, Platte County, Wyoming, through the courtesy of, and in company with, George E. Condra, of the Nebraska Geological Survey.

The placement of formational contacts in a well such as the Agate test, so far removed from control points, is difficult. However, since the results of Mr. Carmody's study are not in entire accord with the Union's determinations we have been asked to record our determinations for comparative purposes. These tops are:

Depth in Feet	
Surface to 1,010	Tertiary
3,635	Pierre shale
3,865	Niobrara chalk
4,625	Benton group
4,725	Dakota sandstone
4,865	Fuson shale
4,995	Lakota sand
5,165	Morrison
5,409	Sundance
5,785	Spearfish
6,325	Cimarron group (Permian)
5,785 to 5,825	Minnekahta-Day Creek dolomite
5,825 to 5,890	Opeche-Dog Creek shale
5,890 to 6,015	Blaine
6,015 to 6,325	Enid formation
6,848	Hartville (Minnelusa) formation
6,325 to 6,728	Division 1 of Hartville formation (Permian)
6,728 to 6,848	Division 2 of Hartville formation (Pennsylvanian)

The segregation of the Hartville formation in this test into divisions 1 and 2 is based on the separation of the surface outcrops of this formation by Condra and Reed in the Hartville area (Paper No. 9 of the *Nebraska Geo-*

logical Survey, 1935). However, determination of the top of the Hartville formation in this test is still a question of much debate. Division 1 of the Hartville formation as represented in this well contains much anhydrite and salt, some sand, some red shale, and some limestone. Excepting for the salt, the interval corresponds in its lithology with what we have determined as division 1 of the Hartville formation in the Lance Creek field, Wyoming. However, the lithologic character of this interval does not check closely with the surface outcrops of division 1 of the Hartville formation in the Hartville area. Despite this fact the interval from 6,325 to 6,728 feet seems to be properly a part of the Hartville formation and is probably of Permian-Big Blue age. Principally division 1 is a red-appearing section of evaporite rocks and represents a changing facies from surface outcrops. Furthermore, it seems to us that the top of the Hartville formation may not be placed higher than 6,325 feet and certainly no lower than 6,728 feet. There is no question in our minds that the beds below 6,728 feet are Pennsylvanian.

We also entertain some doubt relative to the exact correlations between 4,625 and 4,995 feet. While it seems to us that the correlations as given for this interval in our tabulation are the more reasonable, it also is possible to interpret this interval as having Muddy sandstone from 4,625 to 4,725 feet, Skull Creek shale from 4,725 to 4,865 feet, and then have the entire Dakota-Lakota group represented by the remaining all-too-thin interval from 4,865 to 4,995 feet. Typical Morrison sediments begin at this point.

EUGENE C. REED, Nebraska Geological Survey, Lincoln, Nebraska (discussion received, December 9, 1938). The Nebraska Geological Survey has on file a complete set of samples from the Union Oil Company of California's Agate No. 15–1, Sec. 15, T. 28 N., R. 55 W., and the complete set of cores has been examined at the well. The formation contacts, as determined by the Nebraska Geological Survey, do not agree entirely with the determinations of the Union Oil Company and differ slightly from those of the Gulf Oil Corporation.

The fact that this well is located at some distance from areas where the correlation is well established necessitates a classification of strata with some reservations, and differences of opinion regarding correlation are to be expected. The Nebraska Geological Survey classifies the Agate well as follows.

Depth in Feet	
0–70	Harrison formation
300	Monroe Creek formation
750	Brule clay
960	Chadron formation
3,635	Pierre shale
3,900	Niobrara formation
4,250	Carlile shale
4,285	Greenhorn limestone
4,625	Graneros shale
4,725	Dakota sandstone
4,915	Fuson shale
4,965	Lakota sandstone
5,165	Morrison formation
5,409	Sundance formation
5,785	Spearfish formation
5,825	Minnekahta limestone
6,325	Opeche-Cimarron
6,615	Division 1, Hartville formation
6,846	Division 2, Hartville formation

The formations drilled above 960 feet are Tertiary in age. The Monroe Creek-Brule contact can not be placed with great accuracy due to the fact that the Gering sandstone, normally occurring at the base of the Monroe Creek is here absent or represented by finer-grained material than is typical, the lower part of the Monroe Creek is fine-grained in texture and the upper part of the Brule clay is sandy.

The section drilled from 960 to 1,010 feet is believed to represent the yellowish weathered zone at the top of the Pierre shale. It is the writer's opinion that the Muddy (Newcastle) sandstone equivalent is present in the interval herein correlated as Graneros, and that the sandstone from 4,625 to 4,725 feet is the Dakota sandstone formation. The mottled and vari-colored nature of the Fuson shale, as evidenced in eastern and central Nebraska, does not extend to this part of the state and the mottled section below 4,965 feet is typical Morrison mottling and not of the Fuson type.

The interval from 5,825 to 6,325 feet is probably correctly correlated by the Gulf Oil Corporation but the writer hesitates to attempt so detailed a correlation at this time. The rocks drilled from 6,325 to 6,615 feet are believed to be correlative with Division 1 of the Hartville formation.[3] The upper division of the Hartville formation is subject to considerable lateral variation in the outcrop areas and its base is marked by an unconformity of considerable magnitude. Division 1 is probably Permian and the remainder of the Hartville formation, with the exception of some beds of doubtful age at the top, is Pennsylvanian.

[3] G. E. Condra and E. C. Reed, *Nebraska Geol. Survey Paper 9.*

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

PRACTICAL OIL GEOLOGY, BY DORSEY HAGER

REVIEW BY G. S. DILLÉ[1]
Tulsa, Oklahoma

Practical Oil Geology, by Dorsey Hager. 5th ed. 466 pp., 204 figs., 60 tables. Approx. 7.25×5 inches. Semi-flexible cover. McGraw-Hill Book Company, New York (1938). May be ordered through Association headquarters, Box 979, Tulsa, Oklahoma. Price, postpaid, $4.00.

This is a fifth edition of a well known handbook covering oil geology as encountered by both the operator and the geologist. The text has been dressed up in modern apparel with all the newest methods of prospecting and producing mentioned in some more or less brief form. New chapters have been added dealing with paleontology and geophysics. Also many new illustrations have been included. These additions give the book a modern background and bring to the reader the feeling that as far as man has progressed with oil prospecting this book has kept pace. In general the text should provide a ready reference for brief summaries of every prospecting method now employed and the footnotes and references cited should lead the reader to more detailed information. Extremely careless editing detracts much from the otherwise high plane of the book.

THE INDIAN PENINSULA AND CEYLON, BY G. DE P. COTTER

MIDDLE AND WEST AUSTRALIA, BY E. DE C. CLARKE

REVIEW BY R. D. REED[2]
Los Angeles, California

Regionale Geologie der Erde (Regional Geology of the Earth), Band I, *Die alten Kerne* (The Ancient Coigns), Abschnitt VI, "The Indian Peninsula and Ceylon," by G. de P. Cotter. 66 pp., 21 figs. Abschnitt VII, "Middle and West Australia," by E. de C. Clarke. 58 pp., 22 figs. Akademische Verlagsgesellschaft M. B. H., Leipzig (1938). Price, RM 16.80.

Like Hennig's "Afrika,"[3] the two most recent installments of *Regional Geology of the Earth* are devoted to the *Ancient Coigns*, and are thus not of much direct interest to petroleum geologists. In each of them chief attention

[1] Consulting geologist, 808–809 Atlas Life Building. Manuscript received, November 10, 1938.

[2] The Texas Company. Manuscript received, November 19, 1938.

[3] R. D. Reed, review, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 7 (July, 1938), pp. 929–34.

is naturally given to the pre-Cambrian rocks that crop out most widely in the old "coigns," but there are also good summaries of what is known about the blankets of younger formations that mask parts of the basement.

In India these later formations consist, first, of the Gondwana series, ranging in age from Carboniferous or Permian to Lower Cretaceous; second, of the well known Upper Cretaceous rocks of southern India (Trichinopoli district) ranging from doubtfully Albian to Danian; third, of the great Deccan trap series with interbedded sedimentary strata, probably Danian in age; and finally, of flat-lying post-Mesozoic clay, sand, and limestone strata found along the coastal plains. Many of the last-mentioned strata contain fossils, Middle Eocene to Middle Miocene and a few younger.

The basal Gondwana Talchir formation, a glacial deposit, is of uncertain age, but Cotter favors Upper Carboniferous rather than Permian. Clarke, on the other hand, thinks that all of the supposed Carboniferous and Permo-Carboniferous formations of Central and West Australia will probably be proved to be Permian in age (p. 36).

As to the cause of Paleozoic glaciation, Cotter states,

> Today there is a tendency to accept the theories of continental drift associated with the names of Pickering, Taylor and Wegener.

Both sections will be of chief interest to students of pre-Cambrian rocks and to those economic geologists whose work leads them to study the rich mineral deposits of the vast areas treated. The Australian section includes districts as far east as Broken Hill. Each section contains an index and a brief list of important publications dealing with the same area.

ABOUT PETROLEUM, BY J. G. CROWTHER

REVIEW BY K. C. HEALD[1]
Pittsburgh, Pennsylvania

About Petroleum, by J. G. Crowther. 181 pp., 15 pls. Approx. 5.5×8.5 inches. Cloth. Oxford University Press, London and New York (1938). Price, $2.25.

This book is written for those who are unfamiliar with the petroleum industry. The author apparently has attempted to present in simple language the essential facts and theories that will permit a layman to understand the business of finding, producing, transporting, and refining petroleum.

Unfortunately, the author apparently has no background of familiarity with the petroleum industry, and attempted to summarize and selectively present material with which he was not familiar. As a result, the book is distressingly inaccurate. Some controversial theories are presented as facts and, on the other hand, some well established facts are rated as uncertainties.

For example, he would have geologists distinguish between sediments and igneous rocks by the presence or absence of stratification. He classes all igneous rocks as eruptive. He makes all sediments marine in origin. He would have geologists determine the relative ages of sediments by their comparative thicknesses and deformation aided by the color and size of halos around radio-active minerals.

[1] Gulf Oil Corporation. Manuscript received, November 21, 1938.

It probably is significant that the chapters which the reviewer liked best dealt with the topics with which he was least familiar.

This book is without value for the scientists and technologists. The unfortunate mixture of fact and misinformation makes it of questionable worth for the layman.

THE SAINT PETER SANDSTONE IN KENTUCKY, BY WILLARD ROUSE JILLSON

REVIEW BY FANNY CARTER EDSON[1]
Denton, Texas

The Saint Peter Sandstone in Kentucky, by Willard Rouse Jillson. 46 pp., 1 illus. The Standard Printing Company, Incorporated, Louisville, Kentucky (1938). Price, $1.00.

This little book was read as a paper before Section E of the American Association for the Advancement of Science at its meeting at Indianapolis, Indiana, December 31 1937, and is "designed simply as a summary account of facts and conditions as they are now known and interpreted from drilled wells . . . ," as stated in the author's preface. The book is written in a simple, flowing style easily understood by any layman; the print is large and legible.

The first eight pages contain accounts of the discovery and early descriptions of the Saint Peter sandstone at its type locality near Fort Snelling in Minnesota. The next eleven pages describe early attempts to extend this sandstone into other states. The following twelve pages deal with the Saint Peter sandstone in Kentucky; the log of a well drilled in Estill County, Kentucky, occupies pages 32 to 36 inclusive, and a bibliography covering 10 pages closes the book.

The book is replete with conflicting and unsubstantiated statements such as:

> Today it is an established fact that the Saint Peter is present in Kentucky, particularly in certain Bluegrass counties, and in other areas adjacent on the east and south as far as, and some distance south of the Tennessee line (p. 20).
>
> . . . Shaler briefly referred the rather thick group of shales, thin and lenticular sandstones, limestones, dolomitic limestones, and dolomites that lay under the lowest exposed Chazyan beds (Camp Nelson limestone), in central Kentucky as the *Calciferous Series* and sometimes as the *Calciferous Sand Rock* (p. 15).
>
> Apparently it never occurred to Shaler that the generally thin and frequently absent sandstone occurring at the top of his *Calciferous* formation . . . was actually a thin, but nevertheless a true southeastern extension of the Minnesota, Iowa, Wisconsin, Illinois, and Missouri *Saint Peter Sandstone!* But such it was, and is, as has now been proved by Meacham and McQueen beyond the slightest doubt (p. 16).[2]
>
> At the top of his [Hoeing's] *Calciferous* section he mentions the occasional presence of a "hard, greenish white sandstone or quartzite." Hoeing cites its specific occurrence in the White Oak wells in Estill County . . . , calling it the "White Oak Sand of Estill County." It was the *Saint Peter Sandstone!* (p. 19).

In spite of Jillson's apparent recognition (evidenced by the cited quotations) that the stratigraphic position of the Saint Peter sandstone in Kentucky would not be below the top of the *Calciferous* (lower Magnesian) forma-

[1] Manuscript received, November 27, 1938.

[2] Reviewer's note.—Reference is given in a footnote to Meacham's work, but no reference to McQueen is cited.

tion, he nevertheless placed the Saint Peter sandstone 185 feet below the top of his lower Magnesian and Calciferous division of the Ordovician system, in the log of the Wood Oil Company's Rogers well No. 1. ("Samples of cuttings examined and interpreted by W. R. Jillson") (p. 35).

The reviewer feels that Jillson's book offers no proof and no reasonable evidence that the Saint Peter sandstone is present as such in Kentucky. In view of the present oil activity spreading from Illinois into near-by states, she believes it unfortunate that many uninformed operators may be misled by this book, and by such statements as:

> Oil occurred in the Saint Peter in southeastern Clinton County near the Tennessee line. Although the volume of oil was small in this well, its occurrence in this siliceous Ordovician bed in any amount is of the utmost significance as it outlines a broad area closely adjacent in Kentucky and Tennessee where, other geological factors being favorable, it may be quite worthwhile to carry forward further exploration looking toward the recovery of oil in commercial quantity from the Saint Peter sandstone and adjacent horizons (p. 28).

The reviewer wishes further to call attention to the paper just published by Norval Ballard, an experienced stratigrapher, in which he shows the Saint Peter sandstone absent in the well cited by Jillson (the Wood Oil Company's Rogers No. 1), and in which he states:

> The writer has examined cuttings from all available deep wells in Kentucky and Tennessee and believes . . . that these sandstones are eastern representatives of several sandstones that occur in the Beekmantown outcrops in Arkansas and Missouri. . . . similar sandstones are found below the Saint Peter in the Beekmantown in Michigan, Indiana, Illinois, Missouri, and Arkansas. Therefore, until proved incorrect, the writer prefers to consider the age of the Saint Peter as pre-Black River instead of pre-Stones River. . . . The constancy of this [Trenton-lower Magnesian] interval leads one to believe that the sandstone grades into limestone across the Michigan basin just as it does farther south. . . . the writer believes that the Saint Peter as a sandstone is probably absent in eastern Michigan, eastern Indiana, Ohio, Kentucky, and Tennessee.[3]

RECENT PUBLICATIONS

GENERAL

"Search for New Oilfields," by J. Roberts. *Petrol. Times* (London), Vol. 40 (August 27, 1938), pp. 269–71. *Abstract in *Jour. Inst. Petrol. Tech.* (London), Vol. 24, No. 180 (October, 1938), p. 380 A.

*"Report of the Committee on Sedimentation, 1937–1938," Parker D. Trask, chairman. *Nat. Research Council* (Washington, D. C., September, 1938). Presented at the annual meeting of the Division of Geology and Geography, National Research Council, April 30, 1938. Includes the following articles: "Terminology of the Chemical Siliceous Sediments," by W. A. Tarr; "German and Austrian Papers on Mechanical Analysis," by H. C. Stetson; "Bibliography Relating to Organic Content of Sediments," by P. D. Trask; "Unpublished Theses on Sedimentation in American Colleges and Universities," by P. D. Trask; "Sedimentation Studies by the Soil Conservation Service, 1937–1938," by Carl B. Brown. 114 mim. pp. Price, $0.15. Order from Division of Geology and Geography, National Research Council, 2101 Constitution Ave., Washington, D. C.

[3] Norval Ballard, "Stratigraphic and Structural History of East-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 11 (November, 1938), p. 1538.

*"What Life Has the Oil Age?" by A. T. Shurick. *Oil Weekly* (Houston), Vol. 91, No. 10 (November 14, 1938), pp. 64–82; 6 figs.

*"Recognition and Significance of Multiple Erosion Surfaces," by John L. Rich. *Bull. Geol. Soc. America* (Washington, D. C.), Vol. 49, No. 11 (November 1, 1938), pp. 1695–1722; 2 figs.

*"Neocene Spondyli from the Southern United States and Tropical America," by Katherine Van Winkle Palmer. *Palaeontographica Americana* (Ithaca, New York), Vol. 2, No. 8 (October 29, 1938). 19 pp., 3 pls.

Les Gisements de Pétrole, Géologie, Statistique, Économie (Petroleum Deposits, Geology, Statistics, Economics), by George Macovei. 502 pp., 222 figs. Contains chapters on the origin and migration of petroleum, economics and descriptions of petroliferous regions. Masson & Cie, Paris (1938). Price, 120 fr. (approx. $3.00).

Geomechanik. Entwurf zu einer Physik der Erdgeschichte (Geomechanics, Sketch of the Physics of Earth History), by Gerhard Kirsch. 151 pp., 43 figs. Large octavo. J. A. Barth, Leipzig (1938). Price: RM 14.80; cloth, RM 16.

*"Structural Petrology," by Eleanora Bliss Knopf and Earl Ingerson. *Geol. Soc. America Mem. 6* (November, 1938). 270 pp., 27 pls., 81 figs. Approx. 6.75×10.125 inches. Cloth.

LOUISIANA

*"Contributions to the Pleistocene History of the Florida Parishes of Louisiana," by Harold N. Fisk, Horace G. Richards, Clair A. Brown, and William Campbell Steere. *Louisiana Geol. Survey Bull. 12* (New Orleans, September, 1938). 137 pp., 8 figs., 15 pls.

MEXICO

*"Studies of the Mexican Geosyncline," by Ralph W. Imlay. *Bull. Geol. Soc. America* (Washington, D. C.), Vol. 49, No. 11 (November 1, 1938), pp. 1651–94; 6 figs.

MICHIGAN

*"Geology of Allegan County and the Surrounding District in Southwestern Michigan," by R. B. Newcombe. *Oil and Gas Jour.* (Tulsa), Vol. 37, No. 29 (December 1, 1938), pp. 32–34; 1 map.

MISSISSIPPI

*"Columbus Anticline, Lowndes County, Mississippi." *U. S. Dept. Interior P.N. 44947* (December, 1938). 2 mimeographed pp. and geologic map. Reconnaissance survey by Watson H. Monroe of U. S. Geological Survey.

MISSOURI

*"The Geology of Northwestern Missouri," by H. S. McQueen and F. C. Greene. *Missouri Geol. Survey*, Vol. 25, Ser. 2 (Rolla, 1938). 217 pp., 7 pls., 11 figs., 3 tables. 6.375×10 inches. Paper cover. Price, $1.00.

*"Subsurface Geology of Northwestern Missouri," by J. G. Grohskopf,

N. S. Hinchey, and F. C. Greene. *Missouri Geol. Survey 60th Bien. Rept.*, Appendix 1 (Rolla, 1939). 160 pp., 3 pls., 3 figs. 6×9 inches. Paper cover. Price, $1.00.

PERSIA

*"Histoire du Pétrole en Perse jusqu'au Début du XX• Siècle" (History of Petroleum in Persia to the Beginning of the Twentieth Century), by L. Lockhart. *Revue Petrol.* (Paris), No. 810 (November 4, 1938), pp. 1421–25; 1 map.

RUSSIA

"Samara Loop," by D. M. Preda. *Monit. Petrol. Roum.*, Vol. 39 (1938), No. 8, pp. 599–601. *Abstract in *Jour. Inst. Petrol. Tech.* (London), Vol. 24, No. 180 (October, 1938), p. 382 A. Describes Syzran oil field and Jiguli anticline.

TEXAS

"A New Upper Cretaceous Rudistid from the Kemp Clay of Texas," by L. W. Stephenson. *U. S. Geol. Survey Prof. Paper 193-A* (1938). Pp. i-ii, 1–15, Pls. 1–5. Supt. Documents, Govt. Printing Bur., Washington, D. C. Price, $0.25.

UTAH

"The San Juan Country, a Geographic and Geologic Reconnaissance of Southeastern Utah," by H. E. Gregory, with contributions by M. R. Thorpe. *U. S. Geol. Survey Prof. Paper 188* (1938). 123 pp., 26 pls., 4 figs. Supt. Documents, Govt. Printing Bur., Washington, D. C. Price, $0.60.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 12, No. 6 (November, 1938).

"Taxonomy of Mississippian Productidae," by A. H. Sutton.
"Lower Eocene Ostracoda of the Genus *Cytheridea* from Alabama," by Morton B. Stephenson.
"Claiborne Eocene Species of the Ostracode Genus *Loxoconcha*," by Grover Murray, Jr.
"Ostracoda from the Mauch Chunk Mississippian of West Virginia," by H. N. Coryell and I. G. Sohn.
"A Catalogue of Foraminifera," by Brooks F. Ellis.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 1 (JANUARY, 1939), PP. 111-114

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of Sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Carlos Mose Ferguson, Midland, Tex.
S. A. Thompson, John E. Van Dall, Walter L. Moreman
Gerald Albert Northrip, Ada, Okla.
Boone Jones, R. A. Whortan, Maurice R. Teis

FOR ASSOCIATE MEMBERSHIP

Howard Raymond Born, Houston, Tex.
J. C. Montgomery, John S. Cruse, Jr., Hillord Hinson
Louis Howard Haring, Jr., San Antonio, Tex.
F. L. Whitney, Hal P. Bybee, Fred M. Bullard
Richard John Hughes, Jr., Shreveport, La.
G. W. Schneider, Harry X. Bay, George M. Clement
Leo Frank Hunt, Lincoln, Neb.
A. L. Lugn, E. C. Reed, E. F. Schramm
John Charles Martin, Jr., Omaha, Neb.
A. L. Lugn, E. F. Schramm, E. C. Reed
Lloyd Clarence Mills, Fort Worth, Tex.
Morgan E. Roberts, Norman L. Thomas, E. F. Schramm
John Calhoun Monk, San Antonio, Tex.
Charles H. Row, F. H. Lahee, F. E. Heath
John Bruce Scrafford, Alice, Tex.
W. M. Winton, Gayle Scott, Richard T. Short
Fred Lewis Smith, Jr., Houston, Tex.
William B. Moore, M. T. Halbouty, F. W. Rolshausen
George Feick Yunck, Clay City, Ill.
H. N. Coryell, L. J. Fulton, Lynn K. Lee

FOR TRANSFER TO ACTIVE MEMBERSHIP

John Evanoff, Caracas, Venezuela, S.A.
Henry Hinds, James A. Tong, F. I. Martin
Louis H. Lukert, Tulsa, Okla.
J. N. Troxell, H. H. Arnold, Jr., Joseph L. Borden
Fred E. Smith, Houston, Tex.
L. P. Teas, F. W. Rolshausen, Alva C. Ellisor

George E. Wagoner, Tulsa, Okla.
E. V. Whitwell, E. B. Hutson, L. Murray Neumann
Pollok A. Wallace, Tulsa, Okla.
Dollie Radler Hall, Jess Vernon, Jack M. Copass
Karl Louis Walter, Lafayette, La.
Max Bornhauser, C. E. Dobbin, Glenn C. Clark
(Continued on page 120)

TWENTY-FOURTH ANNUAL MEETING, OKLAHOMA CITY, MARCH 22–24, 1939

Revising original announcements about the meeting place of the twenty-fourth annual meeting of the Association in Oklahoma City, March 22, 23, and 24, 1939, the general committee, R. W. Laughlin, chairman, has arranged for the greater convenience of the members to hold the convention at

the Skirvin Hotel. The Skirvin Hotel is convention headquarters. Room reservations should be made individually by communicating directly with the Skirvin or any other hotel selected. The technical sessions, dinner dance, and scientific exhibits will be held in the Skirvin Tower.

Besides the Skirvin, the following are some of the hotels taking reservations for this convention: Biltmore, Black, Huckins, Kingkade, Park-O-Tell, Sieber, Travelers, and Wells-Roberts.

J. T. Richards, chairman of the technical program, announces the following tentative arrangement of half-day sessions.

Wednesday morning, March 22	General session
Wednesday afternoon, March 22	Permian Basin symposium
Thursday morning, March 23	Mid-Continent Pennsylvanian area
Thursday afternoon, March 23	Economics and Recent Development
Friday morning, March 24	Mississippi Embayment
Friday afternoon, March 24	North-Central states

A preliminary list of papers, subject to revision, follows.

DONALD C. BARTON, Humble Oil and Refining Company, Houston (presidential address): Correlation of Crude Oil with Special Reference to the Gulf Coast

E. H. SELLARDS, University of Texas Bureau of Economic Geology, Austin (presidential address, Society of Economic Paleontologists and Mineralogists)

F. M. KANNENSTINE, Independent Exploration Company, Houston, Texas: Relation of Geophysics and Geology

W. H. TWENHOFEL, University of Wisconsin, Madison: The Problem of Origin of Black Shales

CARL O. DUNBAR, Yale University, New Haven, Connecticut: Type Permian of Russia and Permian of the World

VAUGHN W. RUSSOM, Sinclair Prairie Oil Company, and JOSEPH H. MCCOY, Magnolia Petroleum Company, Chickasha, Oklahoma: Stratigraphy and Surface Geology of the Anadarko Basin Region

SHERWOOD BUCKSTAFF, Shell Petroleum Corporation, Tulsa, Oklahoma: The Permian of Oklahoma

GEORGE H. NORTON, Atlantic Refining Company, Wichita, Kansas: Permian Red Beds of Kansas

F. P. SHEPARD, Scripps Institution of Oceanography, La Jolla, California: Recent Studies of the Ocean Floor off California

SIDNEY SWENSRUD, assistant to the president, Standard Oil Company of Ohio, Cleveland: The Relation between Crude Oil and Product Prices

WALLACE PRATT, vice-president, Standard Oil Company of New Jersey, New York City: The Basis for Proration in Texas

ROBERT H. DOTT, director, Oklahoma Geological Survey, Norman: Regional Geology of Oklahoma

IRA H. CRAM, The Pure Oil Company, Tulsa, Oklahoma: Regional Structure of the Mid-Continent Area

H. S. MCQUEEN, Missouri Geological Survey, Rolla: Geology of the Forest City Basin

L. E. WORKMAN, Illinois State Geological Survey, Urbana: Subsurface Geology of the Chester Series in Illinois

N. W. BASS, H. M. SMITH, *et al.*, U. S. Geological Survey, Tulsa, Oklahoma: Relationship of Oils in Mississippian Limestone and Shoestring Sands of the Cherokee Shale in Osage County, Oklahoma, and a Part of Southeastern Kansas

Titles and abstracts of manuscripts to be offered for the A.A.P.G. program should be sent to the subchairmen for the various sessions, as shown below, not later than February 1, 1939.

General Session: J. T. Richards, Box 1557, Oklahoma City
Permian Basin: Ronald K. DeFord, Box 865, Midland, Texas
Mid-Continent-Pennsylvanian: N. W. Bass, Box 311, Tulsa
Economics and Recent Development: R. J. Riggs, Box 591, Tulsa
Mississippi Embayment: Perry Olcott, Box 2180, Houston
North-Central States: A. H. Bell, 305 Ceramics Building, Urbana, Illinois

Titles and abstracts for the program of the Society of Economic Paleontologists and Mineralogists should be sent to C. G. Lalicker, School of Geology, University of Oklahoma, Norman, Oklahoma.

The annual meeting of the Association business committee will be held as usual, at 2:00 P.M., Tuesday, March 21, the day preceding the technical sessions.

A. I. Levorsen, chairman of the research committee, is arranging for the informal dinner of the committee at 6:30 P.M., Tuesday, March 21. At 8:00 P.M., following the dinner, the committee holds its open meeting and discussion.

The annual dinner dance will be in the Silver Glade room of the Skirvin Tower on Thursday night, March 23.

The scientific exhibits will be placed on the balcony above the lobby floor of the Skirvin Tower.

The Society of Economic Paleontologists and Mineralogists will hold its thirteenth annual meeting and the Society of Exploration Geophysicists will hold its tenth annual meeting concurrently with the Association convention.

(Continued on page 119)

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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Memorial

MERRILL EVANS LAKE
(1902–1938)

Merrill Evans Lake died at Mattoon, Illinois, on September 8, 1938, following an accidental fall from a window.

He was born in Buffalo, New York, August 17, 1902, and moved to Los Angeles, California, early in life where he attended public school. He entered Stanford University in 1920 but left before graduation in 1924 to do geological reconnaissance for the Shell Petroleum Corporation of California. He came back to Stanford in 1926, received the bachelor of arts degree in geology, and, after graduation, became field geologist and later petroleum engineer for the Richfield Oil Corporation, Los Angeles. In 1931 he became a consulting geologist with headquarters in Los Angeles, and in 1934 joined the Travis Petroleum Company as geologist and secretary-treasurer. He continued in this capacity until 1936 and at the time of his death was vice-president of the Lincoln Petroleum Company, of Oklahoma City, and the Coast Line Oil Corporation of San Antonio, Texas. From 1934 he had been associated with Ray T. Moore, Tulsa, in the aforementioned companies.

He was a member of the American Association of Petroleum Geologists and the Geological and Mining Society of American Universities. Mike was also a member of the Kappa Alpha fraternity, and the Oklahoma Club.

His was an exceptional personality endowed with a fine sense of humor and genial good fellowship. His passing is a distinct loss to a host of friends in California, the Mid-Continent, Gulf Coast, and elsewhere. For all Mike's genial appearance and ever ready smile he was a hard worker and irrevocably bound to the oil business. That he had vision and perseverance in his chosen field is attested by the measure of success he and associates achieved in acquiring production.

He is survived by his widow, Maxine Lake, of Weslaco, Texas, and a son, George, age 13, of Los Angeles, California.

FREDERIC A. BUSH

TULSA, OKLAHOMA
November 19, 1938

CECIL LAMAR CHATMAN
(1902–1938)

Cecil LaMar Chatman died, October 25, 1938, at the home of his mother in Shawnee, Oklahoma, where he had been taken at his request. Death resulted from a glandular ailment and progressive anemia from which he had suffered for some time.

Mr. Chatman was born in Shawnee, Oklahoma, March, 7, 1902, and attended the public schools there. From 1921 to 1925 he was a student of geology at the University of Oklahoma from which institution he was graduated with a bachelor of science degree. September 1, 1925, he was employed by the Humble Oil and Refining Company and remained in the continuous

service of that company until his death. During these 13 years he engaged in almost every phase of petroleum geology, doing drafting, detailed and reconnaissance mapping, subsurface correlation, and construction of subsurface contour maps. His dexterity in the use of the plane table and alidade and the neatness of his completed work won the admiration of all who were privileged to collaborate with him in detailed mapping. From 1934 until his death he was occupied with production geology, and for the last 2 years resided at Wink, Texas, where he was in charge of the geologic phase of his company's drilling operations in that area. It was in this particular line of endeavor that Mr. Chatman did his best work. He became a member of the American Association of Petroleum Geologists in 1926.

Cecil Chatman was a geologist of ability and unquestioned integrity. His pleasant personality, good humor, and willingness to cooperate made him liked by all who knew and worked with him. His interest in his work never lagged, and he was uncomplaining when his duties demanded long hours of extra time which was often the case. His careful attention to his work even to the smallest detail made of him a very dependable employee. He was a devoted husband and father and his amiable disposition enabled him readily to make and keep friends. In his early death his family, friends, and associates have sustained a great loss.

Mr. Chatman is survived by his wife, Roberta Coffin Chatman, to whom he was married, November 30, 1930, and two children, Phillip Kirk, age 5, and Cynthia Margaret, age 3.

V. C. MALEY

MIDLAND, TEXAS
November 21, 1938

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

EVERETT S. SHAW sailed from New York on November 26 for Buenos Aires to do geological work in the Republic of Argentina. He may be addressed in care of the Yacimientos Petrolíferos Fiscales, Buenos Aires, Argentina.

FRANK A. OYSTER has temporarily closed his office in Abilene, Texas, and has opened a consulting office in Owensboro, Kentucky.

"The Earth's Rocky Crust," "Wearing away of the Land," "The Work of Running Water," are the titles of the motion pictures with the accompanying sound lectures presented by M. T. HALBOUTY, Houston, at a meeting of the Houston Geological Society, November 22.

E. V. WINTERER and ROLLO TURNER, Superior Oil Company, sailed on the Matson liner, *Mariposa*, from Los Angeles on October 14, for an indefinite assignment in New Zealand.

HOWARD F. NASH has changed his address from the Colombian Petroleum Company, Apartado 100, Cucuta, Colombia, to The Texas Petroleum Company, Apartado 427, Maracaibo, Venezuela.

KARL L. WALTER, formerly with the Continental Oil Company, has accepted a position with the Atlantic Refining Company of Cuba, and may be addressed at Havana, Cuba.

At the convention of the A.P.I. in Chicago, on November 16, F. H. LAHEE, Sun Oil Company, Dallas, Texas, spoke before the Institute of Petroleum Technologists on "Geophysical Methods of Exploring for Oil."

WILLIAM D. OWSLEY, designing engineer, Halliburton Oil Well Cementing Company, Duncan, Oklahoma, addressed the Panhandle Geological Society, Amarillo, Texas, on "Squeeze Cementing and Modern Well Completion," December 8, 1938.

J. J. JAKOSKY, technical director of International Geophysics, Inc., recently spoke to the Panhandle Geological Society, Amarillo, Texas, on "The Echo-Meter Method of Measuring Fluid Levels in Wells," and "The Electrical Profile Method of Geophysical Exploration."

EDWARD W. RUMSEY, geological scout, Shell Petroleum Corporation, Amarillo, Texas, has been advanced to district geologist, replacing JOHN E. GALLEY, who has been transferred to Tulsa, Oklahoma.

W. D. HENDERSON, Stanolind Oil and Gas Company, was recently elected president of the Panhandle Geological Society, Amarillo, Texas, replacing BEN L. PILCHER, The Texas Company, recently transferred to Fort Worth, Texas.

C. E. DOBBIN, United States Geological Survey, Denver, Colorado, spoke before the Rocky Mountain Association of Petroleum Geologists at Denver, December 5, on "Some Unusual Types of Overthrusting."

R. H. WOOD showed "Colored Moving Pictures of Mexico," and JAMES H. GARDNER spoke about "Clays and Related Substances," before a meeting of the Tulsa Geological Society on December 5.

L. R. FORTIER has resigned his position with the Shell Petroleum Corporation at Bakersfield, California, and now may be addressed at 1319 South Carson, Tulsa, Oklahoma.

S. S. GOLDICH, department of geology, Texas Agricultural and Mechanical College, College Station, Texas, spoke before the Houston Geological Society about the influence of weathering on the sources and materials of sediments.

W. BAXTER BOYD, Continental Oil Compnay, Ponca City, Oklahoma, recently discussed the Jesse pool before the Shawnee, Oklahoma, Geological Society.

The West Texas Geological Socety, Midland, Texas, has elected the following officers: president, ROBERT E. KING, Shell Petroleum Corporation, Midland; vice-president, H. D. PENNEL, Amerada Petroleum Corporation, Midland; secretary-treasurer, W. Y. PENN, consulting geologist, Midland.

K. WASHINGTON GRAY, formerly with the Anglo-Iranian Oil Company, Melbourne, Australia, has been transferred to the Australasian Petroleum Company, Pty., Ltd., as chief geologist, at Port Moresby, Papua. J. N. MONTGOMERY, formerly with the Oil Search, Ltd., Sydney, Australia, has been appointed assistant to Gray.

Mr. and Mrs. ROBERT W. LANGE announce the birth of Mary Louise Lange, September 1, 1938. Lange is with the Amerada Petroleum Corporation in Los Angeles, California, and may be addressed at 417 South Hill Street.

H. HEMMINGS, formerly with the Caribbean Petroleum Company at Maracaibo, Venezuela, may be addressed at Bataafsche Petr. Mij., Carel van Bylandtlaan 30, 's- Gravenhage, Holland.

JOHN R. GISBURNE, who received the degree of bachelor of science in geology at the University of New Hampshire in 1938, has been employed in the exploration department of the Shell Petroleum Corporation.

DAN O. HOWARD, Oklahoma Corporation Commission, has been elected president of the Oklahoma City Geological Society. Other officers recently elected for 1939 are: vice-president, R. G. HAMILTON, Schlumberger Well Surveying Corporation; secretary-treasurer, BOB HANCOCK, Magnolia Petroleum Company.

TWENTY-FOURTH ANNUAL MEETING, OKLAHOMA CITY, MARCH 22–24, 1939

(Continued from page 113)

Attendance at recent Association meetings has been record breaking. At Tulsa, in 1936, the registration was 1847; at Los Angeles, in 1937, it was 1062; at New Orleans, in 1938, approximately 1850. At the beginning of 1936, the total membership was 2169; in 1937 it was 2331; in 1938 it was 2646; and now at the beginning of 1939, it is at a new high of 3000, and increasing at the rate of more than one a day. Oklahoma City is centrally located for a majority of members and their friends in the petroleum industry. The twenty-fourth annual meeting may set a new record in attendance. Those planning to attend should bear in mind that many members will arrive in the convention city as early as Monday, March 20; that a convention crowd will be on hand, Tuesday, March 21, when the scientific exhibits will be in place and the several Association committees will be in session; and that the technical program begins on Wednesday, the 22nd, and continues through Thursday, the 23rd, and Friday, the 24th.

Requests for reservations for hotel rooms should be made early in advance, directly with the hotel of your choice, and it is suggested that confirmation of the reservation be secured.

OKLAHOMA CITY HOTELS AND RATES

Hotel, Location, and Distance from Headquarters	*Total Rooms*	*Rooms Available*	*Rates*
SKIRVIN HOTEL			
First & Broadway	450	225	Single $3.00 to $4.00
Headquarters			Double 3.50 to 6.00
BILTMORE HOTEL			
Grand & Harvey	600	300	Single 2.50 to 5.00
4 blocks			Double 3.50 to 6.00
BLACK HOTEL			
Grand & Hudson	200	65	Single 2.50 to 3.00
5 blocks			Double 3.50 to 4.00
HUCKINS HOTEL			
Main & Broadway	265	100	Single 2.50 and up
1 block			Double 3.50 and up
KINGKADE HOTEL			
19 West Grand	225	100	Single 2.00 to 2.50
2 blocks			Double 3.00 to 3.50
PARK-O-TELL			
26th & Lincoln	90	25	Single 2.50 to 3.00
Suburban, 3 miles			Double 3.00 to 4.00 (Includes garage)
SIEBER HOTEL & APTS.			
12th & Hudson	60	30	Single 2.00 and up
14 blocks			Double 3.00 and up
TRAVELERS HOTEL			
4th & Robinson	50	25	Single 1.00 to 1.50 without bath
4 blocks			Double 1.50 to 2.00 without bath
			Single 1.50 to 2.00 with bath
			Double 2.00 to 3.00 with bath
WELLS-ROBERTS HOTEL			
15 North Broadway	200	75	Single 2.00 to 3.00
1 block			Double 3.00 to 4.00

NOTE: Several of the rooms available at the Biltmore and Sieber hotels will accommodate as many as 6 persons per room. Several of the rooms in the Huckins Hotel are air-conditioned.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

(Continued from page 112)

FOR ACTIVE MEMBERSHIP

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Consulting Geologist
2062 N. Sycamore Avenue
LOS ANGELES, CALIFORNIA

PAUL P. GOUDKOFF
Geologist
Geologic Correlation by Foraminifera and Mineral Grains
799 Subway Terminal Building
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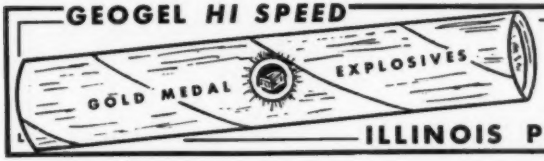

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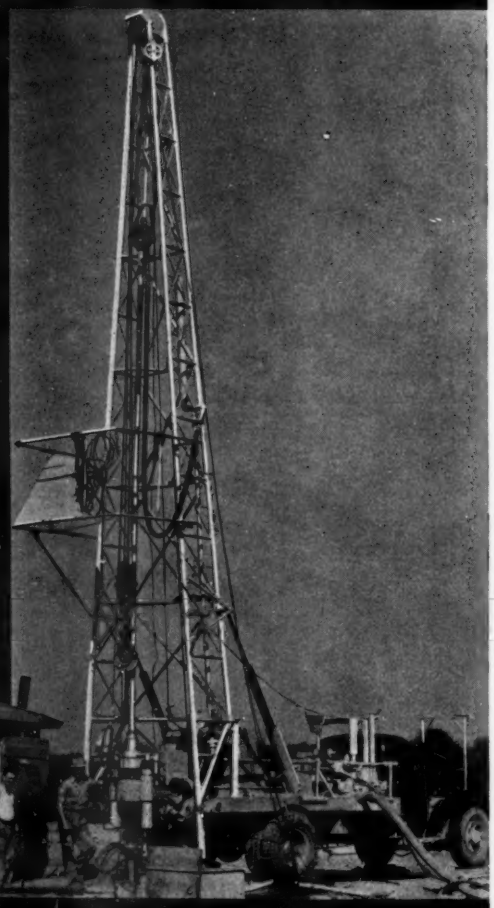

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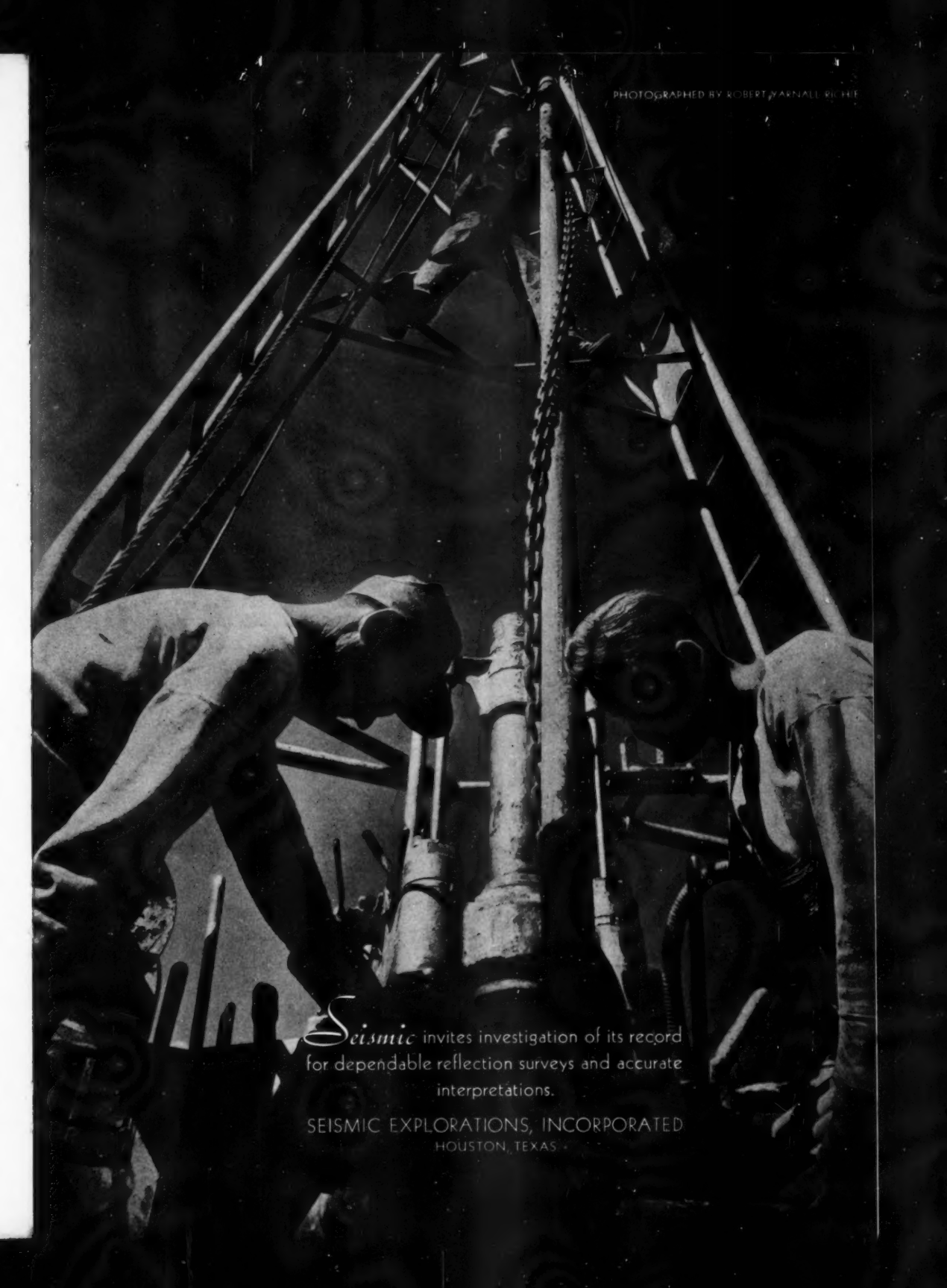

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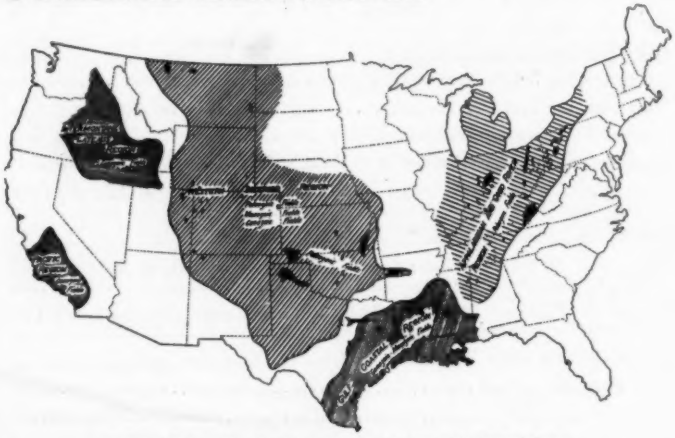

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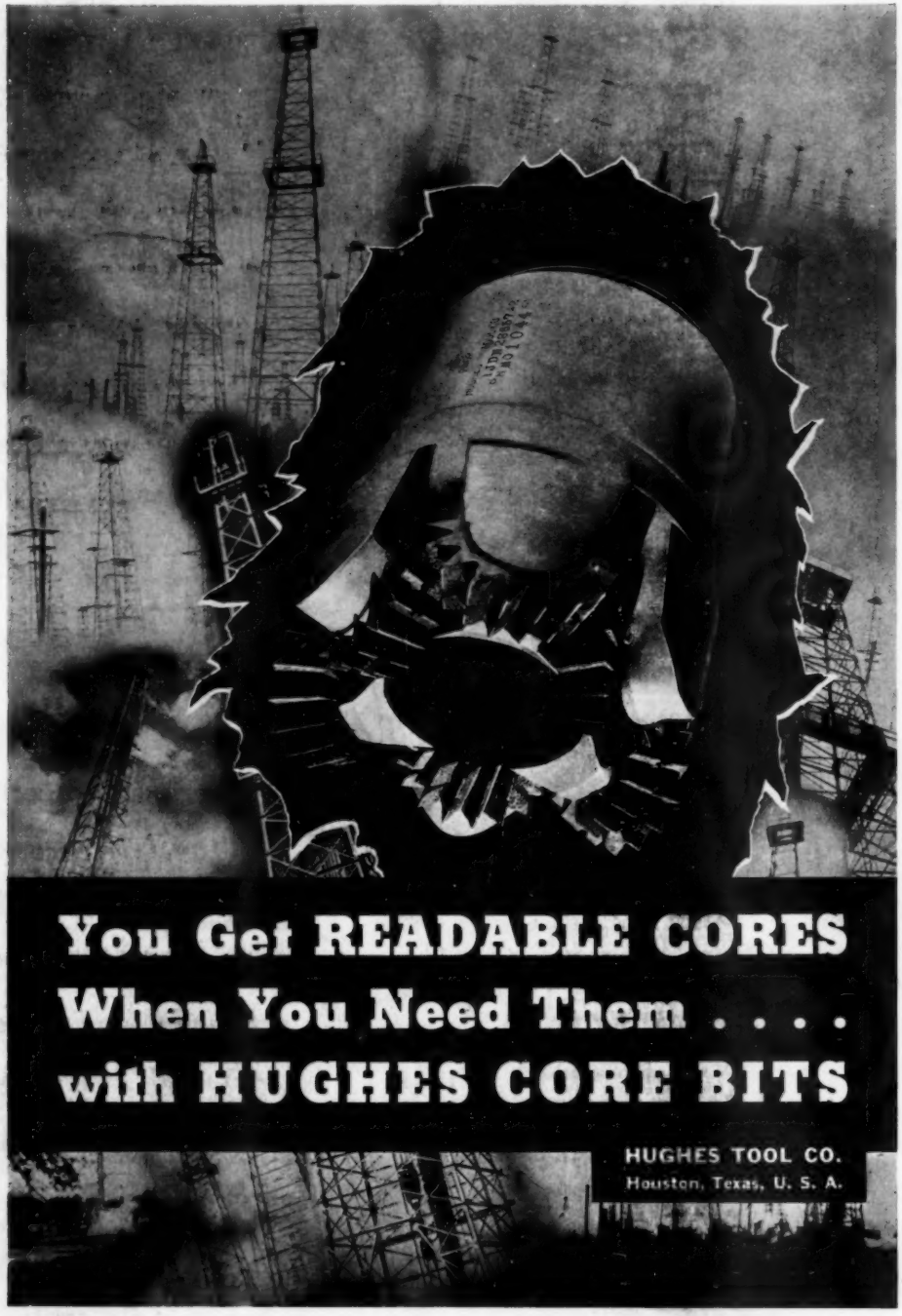
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